

WEST AFRICAN CACAO RESEARCH INSTITUTE



ANNUAL REPORT

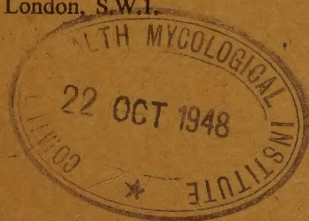
April, 1946 to March, 1947

TAFU, GOLD COAST

Published on behalf of the West African Cacao Research Institute by the
Crown Agents for the Colonies, 4, Millbank, London, S.W.1.

1948.

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WEST AFRICAN CACAO RESEARCH INSTITUTE.

ANNUAL REPORT : 1st APRIL, 1946 TO 31st MARCH, 1947.

SENIOR STAFF LIST AS AT MARCH 31st, 1947.

Director	O. J. VOELCKER, M.A., A.I.C.T.A.
Principal Research Officer	J. WEST, B.S.A., A.I.C.T.A.
Division of Entomology	J. NICOL, B.Sc. (For.), A.R.P.S. D. J. BILLES, B.Sc., A.R.C.S., A.I.C.T.A., F.R.E.S. R. G. DONALD, B.Sc., A.I.C.T.A., F.R.E.S. G. WILLIAMS, B.Sc., A.I.C.T.A.
Division of Pathology and Botany.	A. F. POSNETTE, B.A., A.I.C.T.A. A. H. STRICKLAND, M.A., A.I.C.T.A., F.R.E.S. J. Mc.A. TODD, B.Sc., A.I.C.T.A. H. OWEN, B.Sc., A.I.C.T.A. N. F. ROBERTSON, B.Sc., Dip. Ag. Sc. H. R. EVANS (Horticulturist). D. W. GOODALL, B.Sc., Ph.D., D.I.C., F.L.S., A.R.C.S. (Physiologist).
Division of Soil Science and Chemistry.	C. F. CHARTER, M.A. J. A. R. MACLEAN, B.Sc., Ph.D., A.R.I.C.
Division of Agronomy and Station.	R. J. BENSTEAD, N.D.A., C.D.A. D. WESTWOOD, B.Sc., A.R.C.S.
Secretary	G. H. NEAL, F.R.S.A., F.I.P.A.
<i>Supernumerary:</i>	
Construction Engineer ...	MAJOR C. ALDERSON, D.S.O., E.D., B.Sc., M.I.Mun. and Cy.E.

WEST AFRICAN CACAO RESEARCH INSTITUTE.

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I. POLICY AND ORGANIZATION.

COMPLETION OF THE FIRST THREE YEARS.

The reorganization of cacao research in West Africa became effective on 1st April, 1944 when the creation of a temporary research scheme to investigate cacao diseases and pests took place. This scheme has developed into the West African Cacao Research Institute and the scope of investigations has been broadened to include all matters relating to cacao. The opportunity is taken in this report of summarising the results achieved during the past three years. It will be appreciated that many of these results are the direct outcome of work initiated by Departments of Agriculture prior to 1944. The Institute has indeed been fortunate to have inherited not only certain buildings, land and equipment, but also a nucleus of trained staff already working on a number of cacao research projects.

The summaries of main results achieved will be found at the beginning of each of the relevant sections.

LEGAL CONSTITUTION OF THE INSTITUTE.

An Ordinance, Gold Coast No. 1 of 1947, for the establishment of an Institute to undertake research into matters relating to cacao, for the incorporation of a Committee to manage the Institute and for other purposes connected therewith received the signature of the Governor of the Gold Coast on 12th April, 1947.

Considerable powers, both financial and administrative are accorded to the Managing Committee the membership of which is to be as follows :—

- The Chairman, nominated by the Secretary of State,
- Four members, nominated by the Governor of the Gold Coast,
- Four members, nominated by the Governor of Nigeria,
- The Director, nominated by the Secretary of State.

The Secretary of State reserves over-riding powers, and though, for disciplinary purposes, the Institute's staff will conform to Gold Coast General Orders, the Institute may now be considered largely autonomous. An important aspect of the Ordinance is that staff can now legally be appointed to the Institute. During the past three years staff had either been appointed to the Gold Coast Government and seconded to the Institute or appointed to the Institute which had no legal standing; in either event the element of uncertainty was disliked by the officers concerned.

THE LONDON COCOA COMMITTEE.

This Committee, which was set up in London to advise and co-ordinate lines of research on cacao in the Empire, has now become a sub-committee of the Colonial Agricultural Research Committee. The Committee formed an essential link between the Institute and leading scientific bodies in the Empire, and the Institute has on many occasions received valuable scientific advice and encouragement from the Committee. The Institute regrets that Sir Harold Tempany, C.M.G., C.B.E., formerly Colonial Agricultural Adviser, who was responsible for inaugurating the London Cocoa Committee, has retired. His first-hand knowledge of cacao problems in West Africa and his keen interest in the Institute, the inception of which was so largely due to him, ensured the Institute sound representation in England.

Mr. F. C. Bawden, Head of the Division of Plant Pathology, Rothamsted, and a member of the sub-committee, visited the Gold Coast and Nigeria in January, 1947 to examine the research in progress on swollen-shoot disease and the field method of control. It was gratifying to learn from him that he was in full agreement with both the research programme and the control measures adopted by the Agricultural Departments.

It is hoped that other members of the Colonial Agricultural Research Committee Sub-Committee will visit the Institute in due course.

CACAO RESEARCH AND SURVEY ADVISORY COMMITTEE.

The Advisory Committee met twice during the period under review. The fifth meeting was held at Tafo on 25th and 26th November, 1946. The Nigerian cacao producers' representative was regrettably absent and the Chairman, Sir Gerald Creasy, K.C.M.G., O.B.E., Chief Secretary to the West African Council, was unable to attend the first day. The Committee devoted itself to consideration of technical and financial affairs of the Institute and received progress reports on the Gold Coast and Nigerian cacao surveys. The need for obtaining adequate senior cacao survey staff for the Gold Coast was stressed.

The Committee took the opportunity of examining in some detail the work of the Division of Soil Science and Chemistry and members had explained to them the method of Soil Survey evolved at W.A.C.R.I.

The sixth meeting was held at Tafo on 3rd and 4th February, 1947, under the chairmanship of Sir Gerald Creasy. Again the Nigerian cacao producers' representative was absent and the Chief Conservator of Forests, Nigeria, was unable to attend. The Gold Coast cacao producers' representative was only able to attend the second day's session. The meeting was mainly concerned with the 1947/48 estimates, which were approved, and with the general financial position. It was disclosed that, out of the sum of £1½ million allocated to cacao research, £800,000 had been invested in home Government

securities by the Crown Agents for the Colonies. The interest from and the periodic sale of these securities were estimated to bring in an income of £70,000 for the next six years, and thereafter the income would be reduced until the fund became exhausted 20 years hence.

The balance of approximately £400,000 would meet the cost of the preliminary Gold Coast cacao survey, the detailed Nigerian cacao survey, the capital expenditure of W.A.C.R.I. and the recurrent expenditure already incurred by W.A.C.R.I. for the three years 1944/45 to 1946/47.

In view of the increased costs of equipment and apparatus, and of the upward revision of salary scales, it was considered doubtful whether an income of £70,000 would be sufficient to meet future annual recurrent expenditure of the Institute.

The sixth was the last meeting of the Advisory Committee. With the passing of the W.A.C.R.I. Ordinance the Advisory Committee gives place to the Managing Committee. The Institute owes a debt of gratitude to the members of the Advisory Committee who have, often at considerable personal inconvenience, attended meetings and taken a lively interest in its affairs.

CONFERENCE INTERNATIONALE DU CACAO.

This Conference was held in London on 1st, 2nd and 4th October, 1946, and was attended by those interested in the production of cacao and manufacture of chocolate. Representatives were present from the United Kingdom, Canada, United States, Belgium, Holland, Denmark, France, Sweden and Switzerland. Mr. J. West, Principal Research Officer, represented W.A.C.R.I. At the Conference attention was drawn to the fact that the demand for cacao exceeded production and was likely to continue to do so for a number of years. The reduction in supplies of raw cacao brought about by pests and diseases was noted, and in the course of proposing the toast of the Conference Mr. A. Creech Jones, M.P., Parliamentary Under Secretary (now Secretary) of State for the Colonies remarked on the work being done at Tafo and expressed the hope that even more money would be made available for it.

SENIOR STAFF.

During the period under review four members of the Senior staff left the Institute. Mr. S. H. Crowdy, Pathologist, who drew attention to the association of fungal attack with capsid damage, has been appointed to the Long Ashton Research Station, England. Mr. F. A. Squire, Entomologist, on secondment from Sierra Leone, returned to his post in that colony. Mr. D. A. Richards, Horticulturist, after completing his term of temporary appointment, returned to England. Mr. J. Paine, Agronomist, on secondment from the Gold Coast Agricultural Department, returned to the Department but has been working in close association with the Institute.

Seven new appointments have arrived. Dr. D. W. Goodall, Plant Physiologist, is believed to be the first plant physiologist appointed to British West Africa during the past quarter of a century. His main study is the light requirements of cacao. Dr. J. A. R. MacLean, Chemist, was appointed to strengthen the Soil Science team. Mr. H. Owen, Pathologist, is continuing the mycological investigations started by Mr. Crowdy. Mr. N. F. Robertson, Pathologist, whose post-graduate training included an examination of research in progress on virus diseases in the United States, is working on swollen-shoot disease. Mr. G. Williams, Entomologist, and Mr. H. Evans, Horticulturist, have recently taken up their duties at Tafo.

The Institute has been fortunate to have obtained the services of Major C. Alderson, D.S.O., as Construction Engineer. Major Alderson had recently retired from the Gold Coast Public Works Department; his local knowledge will be of great value in arranging for the construction of new buildings and water works.

The approved Senior staff of the Institute is 20, but two posts remained unfilled and two officers seconded from the Gold Coast Agricultural Department for three years are due to return to the Department in 1947. The Institute will therefore need four senior officers to complete the establishment. Every endeavour will be made to fill these vacancies during the coming year, but it is realised that there is still an acute shortage of trained scientific personnel.

JUNIOR STAFF.

The Junior staff comprises Technical and Senior Technical Assistants and corresponding grades of Clerical and Accounting officers. The posts are pensionable and the salary scales identical with those pertaining to technical and clerical officers in Gold Coast Government Departments. On 1st April, 1944, the Junior staff taken over by W.A.C.R.I. from the Agricultural Department numbered 13; the number has now been increased to 41. Recruitment during the past three years has been made from those with the minimum qualification of School Leaving Certificate (London Matriculation) who have come direct from school or college or who have been in the armed services or who have worked in a non-pensionable capacity at the Institute. There has been no functioning agricultural school during the period in the Gold Coast and the Institute has therefore had to train its own staff. Many of those appointed on probation have proved most satisfactory and will be confirmed. The Institute now is fortunate in having a young and keen Junior staff.

The Institute relies to a considerable extent on non-pensionable assistants, numbering over 100, who hold a minimum qualification of Standard VII certificate. These assistants carry out much of the routine work associated with yield recording, insect population counts, bud-grafting, controlled polination and other activities not necessitating a general training in the biological sciences.

ORGANIZATION.

In the initial two and a half years of the Institute the urgent need for rapid expansion, the lack of staff experienced in Colonial Government procedure and the constantly increased scope of the research programmes necessitated the centralization of financial control. During the latter part of 1946 research programmes became more clearly defined and consequently closer estimates of financial requirements could be made. This, and the appointment of a Secretary, has made possible a reorganization of financial control.

During the coming year it is proposed to delegate control under the following items to heads of divisions:—labour, non-pensionable staff, equipment and travelling. Thus each head of a division will be allocated under these items fixed sums based on his research plans and estimates, and he will be responsible for utilizing the allocations to the best advantage. In order not to overburden divisional heads with routine accounting, a clerical assistant will be attached to each division and all handling of cash will be made by the Secretary's office.

The entomologist working on the insect vectors of cacao viruses has been transferred from the Division of Entomology to that of Pathology, to which his investigations more appropriately belong.

For convenience the physiologist has been attached to the Division of Pathology but this may be regarded as a temporary expedient.

The Division of Soil Science and Chemistry is expected to undergo radical change both in regard to staff and to the scope of work.

During the past year the activities of the Division have been mainly concerned with defining West African soils suitable and unsuitable for cacao cultivation, with evolving a method of soil survey applicable to the forest belt, and with the preparation of detailed soil surveys of the Institute's and Departmental experiment stations. The detailed soil surveys of Tafo and the substations are now complete and much information has been accumulated on the suitability or otherwise of different soils for cacao. A pamphlet, with numerous diagrams, giving notes on how to distinguish good and bad cacao soils was prepared for the use of Agricultural Officers. These notes cannot, however, replace the need for soil surveys of the Gold Coast and Nigerian forest belt to map the actual and potential areas suitable for cacao cultivation. It was agreed that these surveys were beyond the scope of the Institute's activities; just as the Institute, having proved a method of swollen-shoot control, left the executive application of control to the Governments, so, having worked out a method of soil surveying, the practical application would similarly be left to the Governments concerned. The Gold Coast and Nigerian Governments have therefore been invited to consider carrying out soil surveys making use of the technique evolved by the Institute and employing such of the Institute's Senior and Junior staff as are specifically trained in soil surveying. The Institute would further assist by making available laboratory accommodation at Tafo,

If the Governments accept these proposals the Institute will be able to concentrate on soil fertility problems and on fundamental investigations associated with cacao cultivation.

CO-OPERATION WITH THE DEPARTMENTS OF AGRICULTURE.

In the previous annual report reference was made to the close co-operation between the Institute and the Agricultural Departments of Nigeria and the Gold Coast. It is a pleasure to record that this co-operation has been maintained. In the Gold Coast consultations between the staff of the Department and the Institute are frequent. Two examples may be given to show how mutually useful decisions resulting from these have been: the Institute has carried out the detailed soil surveys of the Department's experiment stations at Kumasi, Oyoko and Asuansi; the Department has undertaken the acquisition of land and arranged for the upkeep of cacao virus experiments laid down by the Institute near Wiawso in the Western Province of the Gold Coast.

Distance makes close co-operation with the Nigerian Department more difficult, particularly in view of mail delays and the absence of telephonic communication, but five members of the Institute's Senior staff have visited Nigeria in the period under review. Visits to Tafo by Nigerian departmental officers have been welcome, and that of a party of illiterate Nigerian cacao farmers sent to see for themselves the havoc caused by swollen-shoot in the Eastern Province of the Gold Coast was attended by very favourable results.

In April, 1946 a conference of soil scientists from Nigeria and the Gold Coast was held at Tafo, and the opportunity was taken of learning the views held by French Soil Scientists as expressed by Professor G. Aubert, who was present.

CO-OPERATION WITH FRENCH WEST AFRICAN COLONIES.

The keen interest shown in the Institute by French research officers has been made abundantly clear during their visits to Tafo.

Professor G. Mangenot (Paris) spent several days seeing the work and organization of the Institute; Professor G. Aubert (Paris) discussed in detail soil problems during two visits; M. Alibert, Director of cacao research in the Ivory Coast, has kept in close touch with the latest research developments at Tafo. It has been a pleasure to welcome these and other French Government Officials.

The Senior Pathologist carried out an extensive and instructive tour of the Ivory Coast, and his report thereon received commendation by the British and French authorities.

TAFO STATION.

During the year the amenities of the station have been greatly improved. An appreciable area of bush has been cleared and put down to grass, thereby allowing a view, if not expansive, at any rate not confined to cacao trees and dense vegetation. A small clubhouse has been built and is well patronized. Two tennis courts and a nine-hole golf course supply means of recreation.

The houses have been sprayed monthly with D.D.T. and the incidence of mosquitoes, house flies, cockroaches, ants and silver fish has been reduced to negligible proportions. A note on the method of spraying, costs and results has been prepared and circulated to interested bodies. Since 1st January, 1947, the Senior staff accepted the offer of the Medical Department to act as an experimental unit in testing paludrine. The incidence of malaria has been greatly reduced. The general health of the staff now is considered no worse than that of Europeans in other Gold Coast stations.

The area of the Institute's land is 910 acres. Detailed topographical, geological, soil and forest tree surveys have been completed and, thanks to the Royal Air Force, aerial photographs of the area have been taken.

An additional area of 40 acres was made available to the Institute by the local Native Authority as a building site for African staff quarters. Plans of the layout have been prepared by the Department of Town Planning, and it is hoped that the construction of the buildings will commence shortly.

ACKNOWLEDGEMENTS.

The Gold Coast Government has continued to give every support to the Institute and has continued to advance sums to cover recurrent and capital expenditure. The Institute is particularly grateful to those leading scientists in the United Kingdom who have spent much time and trouble in assisting and advising the Director and his staff.

It is the Director's pleasure to record the good progress made by the Senior and Junior members of the Institute and his thanks are due to the Heads of the Divisions and to other Senior staff who have prepared reports on which the subsequent sections are so largely based.

Owing to shortage of staff the Institute's auditors, Messrs. Cassleton Elliott, have been unable to audit the accounts at the time this report has been prepared. The financial statement given in Appendix 2 is therefore still subject to audit.

II. VIRUS RESEARCH.

SUMMARY.

A large number of virus strains has been recorded in the Ivory Coast, Gold Coast and Nigerian cacao belt. There is a tendency for each locality to be characterized by different symptoms of cacao virus disease; these differences have been faithfully reproduced by transmission at Tafo. Virus disease of cacao has been recorded on all the main soils on which the crop is grown in West Africa.

There is strong evidence that several distinct viruses are concerned. The term "Swollen-shoot Disease" is loosely used to cover all these and their strains though certain are known not to produce stem swellings.

The field vectors of the disease have been determined; *Pseudococcus njalensis* and *Ps. citri* have been found to be of most importance. *Ps. njalensis* has been shown to transmit all cacao virus strains tested. It has further been shown that Strain A can be transmitted by these mealybugs as nymphs or adults, and that they can obtain virus from either the pods, leaves or stems of infected trees in less than four hours' feeding.

Data concerning the bionomics of *Ps. njalensis* have shown that this species has a wide range of indigenous food plants, though certain species are preferred. Owing to the comparatively low population of *Ps. njalensis*, the wide range of their feeding sites and the protection afforded by these and by attendant ant cartons, control by chemicals seems out of the question.

In young nymphal stages the mealybug has been shown to be distributed by wind. At all stages of growth, movement, with or without ants, can occur from tree to tree. This explains the spread of the disease.

A new technique of insect transmission of viruses has greatly quickened and simplified investigations on this subject.

No cacao tree immune to virus has yet been discovered. Varying degrees of tolerance have been shown to occur. Young plants infected with attenuated strains of virus have been shown to react mildly or not at all to subsequent infection with virulent strains.

In mature trees infection by the virulent Strain A precedes visible symptoms by a variable period of several months. Though certain methods of staining can indicate whether a tree is healthy or infected they are not of practical application in the field. Coppicing trees reduces the time in which visible symptoms of latent infections can be distinguished.

No seed transmission of cacao virus has been obtained.

Work on alternative hosts of cacao virus has so far shown that *Thebroma bicolor* and *Cola chlamydantha* can be infected with cacao virus which can, in turn, be transmitted back to cacao. *Cola chlamydantha* is of particular importance since it is indigenous to West Africa, and is also a favoured host of *Ps. njalensis*. Active work on other possible indigenous hosts is in progress.

Control of the spread of swollen-shoot by cutting out infected cacao trees has been proved. In certain outbreaks the control is complete, in others of which the old station at Tafo is an example, re-infection has continued. This may be caused by the ingress of vectors carrying the disease from infected cacao trees in neighbouring farms or by the movement of vectors from infected alternative hosts on the station.

Cacao can be successfully re-established on farms devastated by virus disease provided the soil is suitable. If all diseased cacao trees are first removed the incidence of disease on young re-established cacao is small.

VIRUS STRAINS.

New Strains.

The symptoms of several new virus strains have been determined during the year. Most of the strains concerned were discovered in the Ivory Coast or Western Province of the Gold Coast by W.A.C.R.I. specialists engaged in detailed investigations in those parts; in view of the circumstances of the discovery of the strains, it is likely that research carried out on a similarly intensive scale in other less-known loci of cacao virus would result in the recognition of further strains or strain groups.

The demonstration of a large number of distinct strains within a relatively small area of virus outbreaks has become a feature of all but the most superficial examinations; an excellent example is the group of strains found in the Wiawso district in the Western Province of the Gold Coast. In this group, one or two strains are of fairly wide distribution and frequent occurrence but the majority appear to be confined to a single outbreak or to closely situated outbreaks. Occasionally, within an outbreak, one or more graft-transmissible variations of the virus may be present in a minority of the infected trees. Such is the case in the Kpeve (Strain C) outbreak in Togoland.

Within geographical groups, there may be conspicuous differences in virulence and symptoms between the strains; in spite of this, there is usually a resemblance somewhere in the symptom-picture. In the Wiawso group, large and often elongated chupon swellings, an expansive chlorosis round the tertiary veins or a tendency towards the production of a bright yellow chlorosis unrelated to the veins, are symptoms common to many of the strains. In the New Juaben (Strain A) group, flecking and blocking with eventual reduction of chlorosis to a "fern-pattern" is a characteristic sequence of symptoms.

The results of cross-protection (or acquired-immunity) tests are being used as final criteria of the relationship between strains in geographical groups, while the positive or negative relationship of an arbitrarily chosen member of the group to Strain A is taken to be that of the entire group. By this means, it may soon be possible to compile a new scheme for cacao viruses in which mutually non-protecting forms, hitherto loosely called "strains," will be elevated to the rank of specific viruses, while the word "strain" will be used only in the strict sense to connote close biological relationship. But until the relationships of most of the viruses have been established by these cross-protection tests, the loose usage of the term "strain" will be continued, although it is already clear that several distinct viruses are actually involved.

Comparative virulence of various strains.

At present, established data on this subject are limited to some results obtained from a field experiment involving Strains A, B and C and have already been fully reported (Crowdy, S. H. and Posnette, A. F. 1947. *Ann. Appl. Biol.* 34-3). Continuing the field

work, experimental plots have been set up in the Wiawso district with a view to ascertaining the rates of spread and yield-effects of some of the indigenous strains. Two of the field plots have been designed to be demonstrations of the rates of deterioration of cacao naturally infected within the Amafie and virulent Bosumuoso strains respectively. The trees in each plot have been numbered and spot-planned so that individual tree yields can be recorded. The third experiment is intended to provide comparative figures on deterioration caused by six of the common or otherwise interesting local strains. There are five blocks each of eight plots; each plot measures 40 feet by 40 feet and is separated from its neighbours on all boundaries by a guard lane five feet in width. In each block treatments have been randomized—two “non-inoculated” control plots and six “inoculated” strains plots; there are about 190 trees to each treatment.

A quantitative estimation of the effect of infection by certain well-known strains on the vigour of cacao seedlings is being attempted. Each strain is being indexed by a series of five Amelonado cacao seedlings which were inoculated by patch-grafting when about a year old. Subsequent to inoculation of the seedlings, readings on the incidence of flushing and the leaf-area and symptom-expression of each flush have been made. The records for the extent and degree of chlorosis on the leaves of each flush are purely qualitative, but an appropriate arithmetical expression has been obtained by the allocation of marks to each flush; the marks range in value from one to four, depending on whether the chlorosis is severe, intermediate, mild or absent. Within any period, the sum of marks allotted to the five seedlings in each treatment is the “value” of that series for the period. The symptom values for ten strains and comparative figures on growth-inhibition after a period of eight months’ infection are given in Table 1.

TABLE 1.
THE INCIDENCE OF FLUSHING AND SYMPTOM “VALUE”
OF SERIES OF AMELONADO SEEDLINGS INFECTED FOR
EIGHT MONTHS.

Strain.	No. of growth flushes.	Symptom “value.”
Healthy controls ...	5·8	116
Strain A (New Juaben) ...	2·6	32
Strain A (attenuated) ...	5·6	103
Strain B (Bisa) ...	5·4	106
Strain C (Kpeve) ...	5·8	95
Strain D (Nkawkaw) ...	4·6	63
Strain F (Wiasi) ...	5·2	91
Strain H (Dawa) ...	3·2	38
Strain J (Bosumtwe) ...	4·8	76
Strain K (Konongo) ...	3·8	55
Strain M (Mampong) ...	4·0	73

The order of the strains in terms of symptom value closely approximates to that in which they would be placed from an eye estimate of their field virulence. This does not apply here to Strain C which is much more virulent than would appear from the above table; it is probable that an attenuated form of the strain is being used in the experiment.

Inter-relationships of strains.

Observable differences in symptoms suffice for the discrimination of cacao viruses, but resemblances need not in themselves constitute any reflection of genetical relationship. Close phasic similarity between strains in their development in the plant may, on the other hand, be of some value in indicating a possible kinship, but the final test must be on a physiological rather than symptomatological basis. In this connection, the plant-protection test has been, so far, the only one of real value in the study of cacao-virus inter-relationships. The technique is simple. Seedlings (about a year old) of West African Amelonado are used as index plants; they are first inoculated by patch-grafting with a strain whose symptom-sequence is such that the symptoms of a second virus could be recognized if superimposed on the same plant. Replication is a feature of all tests, and is so arranged that inoculation of the second strain is carried out at various phases in the course of infection of the first. The second inoculations are controlled by grafting from the same source into virus-free plants; conclusions in an immunological test of such a nature are obtained by comparison of the reinoculated and control plants in relation to symptom-expression and length of latent period.

It would appear that there are four degrees of protection:—

1. *Complete protection.*

Examples: Attenuated Strain A against Strain A.

Strain H (Dawa)	„	„
Strain K (Konongo)	„	„

Strains H and K resemble Strain A in the details and sequence of leaf symptom-expression but are slightly less virulent; attenuated Strain A is very unlike the virulent form in all these characters. It rarely produces symptoms and then only an indistinct chlorosis of the finest veins or a sparsely-occurring chlorotic banding of the main veins; the mildest forms of attenuated Strain A rank almost as symptomless viruses. A plant which is infected by attenuated Strain A assumes a resistance apparently of a permanent nature to severe Strain A. A field experiment has been laid down at Tafo to test the effect of an attenuated A Strain on yield and to demonstrate the protection it affords against the severe strain.

2. *Incomplete protection.*

Example: Strain B (Bisa) against Strain A.

Preliminary infection with Strain B delays the appearance of Strain A symptoms, the latent period being usually doubled or trebled.

3. Absence of protection.

Examples: Strain C (Kpeve) against Strain A.

Strain F (Bosumuoso 2) against Strain A.

Strain J (Bosumtwe) " "

Infection by these strains offers no protection against a subsequent infection by Strain A, neither in the latent period nor in the acute and chronic phases; symptoms of Strain A appear after a normal latent period and its own phasic development is not apparently modified by the presence of the milder virus.

4. Absence of protection and the formation of complex.

Example: Strain M (Mampong) against Strain A.

In Strain M-infected plants on which a Strain A-infection is later superimposed, each virus appears to follow its respective course of phasic development regardless of the other. Occasionally, however, a leaf-symptom typical of neither strain develops and it has been assumed to be the visible result of the formation, by coincident development, of a localized complex, which has proved to be transmissible intact by *Ps. njalensis*.

COPPICING OF CACAO.

Field trials were set up to provide information on the effects of coppicing Strain A virus infected cacao trees; the history and early results of the trials have already been given (2nd Ann. Rep., W.A.C.R.I., 1946). Regeneration of old cacao trees by the growth of basal chupons (water shoots) is part of the life-history of the plant and the healthy tree reacts favourably to regenerative treatments such as coppicing and pollarding; only about six per cent. have been found to die as a result. On the other hand, about 80 per cent. of the infected trees in an outbreak of Strain A die within a short time of treatment and the growth of most of the infected survivors is severely checked after the initial growth of the dormant buds. With a few infected coppiced trees, however, growth proceeds almost normally for an indefinite period and virus symptoms become so reduced that the plants may undergo long symptomless phases. The conditions necessary for this apparent recovery have been investigated as possible approaches to the problems of resistance and tolerance. Three hypotheses were followed:—

- (1) Vigorous coppiced trees with mild virus symptoms are infected by an attenuated form of Strain A manifested or induced by the treatment, or
- (2) Such trees are infected by a mild virus which is present in the tree before treatment but is confined to the lower parts of the plant; its properties are masked in the intact tree by a severe virus predominant in the upper parts, or
- (3) Such trees merely tolerate or suppress infection by severe Strain A.

In testing for the predominance of mild virus in vigorous coppiced trees, six were chosen from one outbreak as sources of virus; three of the trees were of the vigorous type but the others were of mediocre or poor growth and characteristic of the majority of temporarily surviving infected coppices. Test plants were year-old Amelonado seedlings graft-inoculated from each source in series of five.

The development of symptoms in the test-plants made possible a comparative estimate of the virulence of the virus introduced from each source. There was a clear-cut distinction between the vigorous and the poor coppiced trees in this respect. The infecting virus from the vigorous trees was mild whereas that from the trees of mediocre or poor growth was virulent; the latter virus was undoubtedly the "common" severe Strain A, while the mild was identical in symptoms to attenuated forms of Strain A such as have been discovered in actively tolerant clones. These results then support either of the first two hypotheses but invalidate the third.

It remained to be discovered which of these hypotheses is true and, if the first, whether the presence of the attenuated strain in the plant is actually a direct result of, or is merely made prominent by, coppicing.

The problem necessitated a study of the infection in intact trees, four of which, representing two phases of infection (two at incipient and two at advanced stages of defoliation) were chosen arbitrarily from the outbreak containing the coppiced trees of the first experiment to serve as sources of virus. The object of this second experiment was to detect any differences in virulence which might occur between the viruses infecting the four trees and in distinct parts of each tree. Graft-pieces were transferred from the following sites on each tree to year-old Alemonado test-seedlings in series of five:—1. The distal, leaf-bearing twigs in the canopy. 2. The older, non-leaf-bearing parts of the fan branches. 3. The basal leaf-bearing chupons (water-shoots) and 4. The lateral surface-layer roots.

The virulence of the virus obtained from each of the 16 sources was estimated on a comparative basis from the symptoms in the test-plants. From all four sites on one tree, fully attenuated virus was transmitted: from a second tree the virus was intermediate in virulence, while from the remaining two trees it was severe. The test-plants inoculated from the lower sites (3 and 4) of all four developed infections of a slightly milder form than did those inoculated from the canopy sites. The extent of this variation was hardly sufficient to validate the second hypothesis, but its occurrence is of interest and is being given further attention.

Thus, it has been shown that Strain A varies in virulence, usually slightly but occasionally over a wide range, from one infected tree to the next within the same outbreak. In view of the potential occurrence of this wide range of variation there is no need to postulate that

attenuation is actually induced by coppicing; the probable effect of the treatment is to render more conspicuous the tree infected with a mild virus. It need not follow that trees which show vigorous growth after coppicing would have survived in the intact form, as coppicing possibly assists survival by placing an abundant supply of sap at the disposal of a few developing buds. In the absence of any regenerative treatment, only the most vigorous trees or those infected with a very mild form of Strain A would survive. Most of the trees from which our naturally infected "resistant" clones have been developed were probably in this category.

Resistance to virulent Strain A virus (New Juaben).

Recent investigations have been concerned with the nature of "resistance" in cacao to the virulent form of Strain A and so far have resulted in the differentiation of types of "resistance." No cacao plant has been found which truly resists infection by grafting unless it is already infected with a mild strain of the virus. Resistance (in the strict sense) to infection by vectors has not been investigated. In the following account, the term "resistance" refers to a form of acquired immunity, due to prior infection with a mild strain while "tolerance" is used to denote the ability of a plant to withstand infection with virulent Strain A, although not previously infected with a mild strain.

Tests for resistance and tolerance to Strain A.

Material has been obtained by the selection of surviving trees in devastated areas and clones have been built up from these by budding first onto Amelonado seedling root-stocks. Subsequent multiplication has been made by using budwood from these clones. When the parent tree was already infected at the time of selection the entire clone has been propagated with a natural infection; but this has not exempted those clones from the routine testing procedure in which a number of the individuals of every clone are infected by grafting with virulent Strain A. So far in these tests, no immunity to Strain A has been found but in some clones, and particularly in certain individuals of such clones, resistance or tolerance is so marked that no symptoms occur for long periods; in these clones absence of symptoms on individual plants can no longer be regarded as an adequate criterion of freedom from infection.

Strain A in resistant and tolerant plants.

It has been considered of first importance to discover whether the virus infecting resistant trees in the field is qualitatively different from the common virulent form of Strain A; and also whether any change had occurred in the virulence of the virus which had been inoculated by grafting into tolerant clones several years previously.

In the first experiment nine clones were chosen to provide virus source plants; four had been naturally infected but were fully resistant

to further inoculations of severe Strain A, while three had been infected by grafting and showed great tolerance. The individual chosen from the eighth clone to provide virus was a tolerant member of an otherwise susceptible clone. The ninth clone was uniformly susceptible and was used as a control. The test-plants were year-old, Strain A-susceptible Amelonado seedlings, inoculated by patch-grafting.

The results are summarised in Table 2.

TABLE 2.
COMPARISON OF VIRUS FROM RESISTANT,
TOLERANT AND SUSCEPTIBLE PLANTS.

Virus source.	Effect on test-plants.
1-4 Resistant clones ...	Mild.
5-7 Tolerant clones ...	
8 Tolerant plant of susceptible clone	Virulent.
9 Susceptible clone ...	
10 Seedling (control)	

The course of infection in the test-plants revealed that fully-virulent Strain A had been transmitted from the control clone (9) and from the single virus-resisting member of the eighth clone. This latter plant which has survived infection for a period of six years and continued in a state of moderate vigour is regarded as an example of the type of reaction usually classified as tolerance. Evidently it possesses the ability to harbour the severe virus indefinitely. With the control clone, the transmission of severe virus was expected; the source plants at the time of selection were showing considerable defoliation though they had been inoculated less than two years previously.

Regarding the seven remaining clones, the test-plants either failed to produce symptoms or produced very mild symptoms on occasional flushes, while growth-rates were not reduced. It was clear that the virus infecting these clones was, in fact, dissimilar to the severe form of Strain A against which it was apparently able to protect the host and from which, in the case of three of the clones (Nos. 5-7) it had evidently evolved.

It remained to be discovered whether resistance is due primarily to the presence of the milder virus as has been suggested above, or to that property of the host which had induced the change in the virus from severe to mild. This involved testing for the coincident transmissibility of mild strain and resistance.

Three months after inoculation from the resistant clones (1-4) the test-plants were divided into three groups according to whether the plants (1) had not shown symptoms, (2) were showing the first phase

of mild symptom-expression on the current flush or (3) had produced one flush with mild symptoms and one or more symptomless flushes in succession. Seven plants of the first group, six of the second and four of the third were then reinoculated by grafting from a source of virulent Strain A from which, in addition, six virus free Amelonado seedlings were inoculated as controls. Within seven months of reinoculation, all but one of the Members of the first group had produced mild virus symptoms but the presence of severe Strain A was not evident in that period in any member of the three groups. Resistance had been transmitted by grafting. On the other hand, the symptoms of virulent Strain A developed typically in the controls. The growth of the reinoculated seedlings was not noticeably impaired; they developed a mean of 4.2 flushes in the seven months following the graft-inoculation of Strain A, as against figures of 3.9 and 2.2 for mild strain-infected and severe Strain A-infected controls respectively.

It would seem then that in these cacao clones, resistance, as distinct from tolerance, might have been acquired by infection of the plant with a mild strain which, it can be assumed from the plant protection test, is an attenuated form of the severe virus.

Types of "resistance."

From the experiment which has just been described and others of a similar nature, it has been concluded that there are three main types of a "resistance" (*sensu lato*) to severe Strain A. The first is a mere state of tolerance whereby the virus continues to be harboured in its full virulence by the host. Tolerance does not appear to be common and there is no known instance of its being characteristic of an entire clone. On the other hand, the second type of "resistance," *active tolerance*, is usually a clonal property and is characterized by the ability of the plant to cause a reaction in its tissues whereby introduced severe Strain A is so changed that an attenuated strain becomes the predominant infecting virus. The third type, *acquired resistance*, can be induced in any cacao plant by artificial infection with the attenuated strain and, of course, necessitates no special property of the host.

Attenuated Strain A and active tolerance.

It has been customary to refer to an attenuated strain in the singular but this has been merely a convenience. Strain A should be regarded as a graded complex comprising an infinite series of sub-strains ranging in their effects from very severe to very mild, but, in practice, the use of "attenuated" has been reserved for those strains which do not produce a continuous sequence of leaf symptoms from flush to flush and with which such severe symptoms as necrosis and defoliation are never produced.

The complex nature of the virus can be rendered evident by certain techniques as where tolerant and susceptible clones are inoculated by grafting from the same source of severe Strain A. When the infection has developed in the various plants, the degree

of virulence of the respective viruses can be determined by graft-inoculation from the clonal individuals to series of susceptible test-seedlings and by subsequent observations on symptoms and frequency of flushing in the latter. In such a test of a group of 12 clones, it was found that the virulence of the inoculated virus had remained substantially unchanged in four of the clones and that attenuation had occurred in five. In the remaining three clones the virus had not been altered in virulence in some members of each clone but had become attenuated in others; such variation between members of a clone is possibly less common than the results of this experiment would suggest but its occurrence is an outstanding reflection of the apparently unstable nature of the virus when methods of graft-inoculation are used.

The attenuation reaction in actively tolerant clones.

An attempt is being made to determine the conditions under which attenuation occurs and work in progress is concerned with the location of the reaction in the actively tolerant plant. Cuttings of various actively tolerant and non-actively tolerant (control) clones are inoculated by patch-grafting from a source of severe Strain A and simple cuttings of each clone are subsequently used as plants from which patch-grafts and potentially virus-carrying mealybugs can be transferred to Amelonado test-seedlings.

The work is as yet incomplete but from results obtained to date, it would appear that the reaction does not take place automatically on the introduction of severe virus to the resistant host, nor during the latent period, but occurs later in the chronic phase of infection.

ALTERNATIVE HOSTS OF SWOLLEN-SHOOT.

The host-range of the Strain A virus has been investigated by three methods. Before a reliable vector technique had been developed, attempts were made to transfer the virus from infected cacao seedlings to seedlings of suspected indigenous species by approach-grafting. Later, mealybugs were used in attempts to transfer the virus to and from alternative host plants, using cacao as the virus source and test plant. Both these methods were successful with *Theobroma bicolor* but failed to give any definite results with indigenous plants, although seedlings of *Bombax buonopozense* developed virus-like symptoms.

The third method is to transfer mealybugs to cacao from plants suspected of natural infection in outbreaks of swollen-shoot, and this has produced definite results; three plants of *Cola chlamydantha* in the Wiawso district have been found to be infected with swollen-shoot. A preliminary survey of *Cola* spp. in the Wiawso district is now in progress to investigate the extent of virus infection in the genus, and in *C. chlamydantha* in particular.

RATE OF SPREAD OF SWOLLEN-SHOOT AND VECTOR POPULATION.

The rate of spread of swollen-shoot (Strain A) and the consequent decline in yield of cacao is being studied on eight acres of station cacao on which no control measures have been taken. When the investigation started in August, 1945, 31 per cent. of the trees were infected; by March 1947, 55 per cent. had become infected. Associated with this increase in swollen-shoot was a 19 per cent. reduction in yield.

The aggregate figure of 24 per cent. in the number of infected trees is made up from numerous independent outbreaks. The spread in these outbreaks has varied from 10 per cent. to 100 per cent. and as this variation was not correlated with tree-density, it was regarded as due to variation in vector populations. In single, circumscribed outbreaks, centrifugal spread rarely occurs uniformly over the whole perimeter, and most outbreaks tend to become more amoeboid than circular in shape.

Vector-population studies have been commenced in this area where previous knowledge of rate of spread is being used in the choice of trees from which to take a mealybug census. The essence of the investigation is to discover whether in zones of active spread, the population of *Pseudococcus njalensis* is relatively higher than in zones where spread has been during the past year negligible. In both types of zone, samples are made of symptomless as well as of infected trees. In small outbreaks, samples of trees are taken along a transect cutting through both "active" and "quiescent" zones, while in larger outbreaks blocks of trees are selected at relevant sections of the perimeter. As the taking of a census involves the cutting down of the tree, a minimum of trees is selected at each locus so that the general shape of the outbreak remains unaltered and observations or rate of spread can be continued in the future. All mealybugs and attendant ants are retained for counting and identification in the laboratory.

As yet, no attempt has been made to correlate rate of spread with populations, but figures are given in Tables 3 and 4 on general populations and the choice of feeding position by *Ps. njalensis*.

TABLE 3.
DENSITY OF MEALYBUG POPULATION.

Date.	No. of trees examined.	No. of trees with mealybugs.		No. of mealybug colonies.	No. of individual mealybugs.*
		Infected trees.	Healthy trees.		
Aug., 1946 ...	79	15	12	103	316
Feb., 1947 ...	71	16	23	314	782

* *Pseudococcus njalensis* and *Ps. citri* only.

As expected, *Ps. njalensis* proved to be the predominant species of mealybug, with *Ps. citri* second. The third known vector of Strain A, *Ferrisia virgata* was not found.

Particular care was taken to record the exact feeding position of each colony, and every pod was counted and examined. Rather surprisingly, the proportion of infected pods was exceedingly low in the August census, when the trees were carrying their maximum number of pods. The canopy was the most favoured location, small cankers and cracks in the bark being the position in which most colonies were found. Most mealybug colonies showed signs of ant attendance. The aggregate figures for the feeding positions of *Ps. njalensis* colonies are given in Table 4.

TABLE 4.

THE DISTRIBUTION OF 91 COLONIES OF *PS. NJALENSIS*
WITH REGARD TO FEEDING POSITION.

(Figures obtained from 20 trees.)

Location Position.	CANOPY.			UPPER TRUNK.		LOWER TRUNK.	
	Leaves.	Bark.	Pods.	Bark.	Pods.	Bark.	Pods.
No. of colonies	8	33	11	6	10	16	7
Totals - ...	52			16		23	

Figures on the incidence of virus disease on re-established cacao in the experimental plots are given in Table 15 of the section, Experimental Plots in Native Farms.

The heaviest infection has occurred at Koransang where 34 out of some 15,000 young plants have become diseased. It will be noted that this station includes areas of mature trees which are themselves being constantly re-infected.

At Akwadum and at Adonkwanta the observation has been made that a single diseased seedling may occur at the same picket with two healthy seedlings. On that half of Adonkwanta where diseased seedlings are not rogued four of the infected plants are at pickets with healthy seedlings. It will be interesting to note whether these healthy seedlings become infected in due course.

Though infection of young cacao on the experimental plots is mainly confined to seedlings adjacent to the plot boundaries, and hence to mature infected cacao, certain seedlings have succumbed at a considerable distance from the nearest diseased cacao. The one and only infected seedling on the Nankese plot was 80 yards from the nearest diseased tree.

VECTORS OF VIRUS STRAINS.

Previous work had demonstrated that the mealybugs, *Pseudococcus njalensis*, Laing. and *Ferrisia virgata*, Ckll. are vectors of the Strain A virus, that all stages of *Ps. njalensis* could transmit, and that the vectors could obtain virus from either pod, leaf, green stem, or bark in less than four hours' feeding. Investigations during the year have been concerned chiefly with feeding times on infected and healthy plants necessary for virus transmission, and with the vectors of viruses other than Strain A.

TABLE 5.

EXTRACTED RESULTS OF SOME EXPERIMENTS WITH
VECTORS AND VARIOUS VIRUS STRAINS.

Virus strain.	Vector species.	No. of insects per plant.	No. of test-plants.	Number infected.
A (New Juaben)	{ Ps. njalensis ...	5	5	5
	{ Ps. citri ...	5	5	5
	{ F. virgata ...	5	12	10
	{ Ps. concavocerarii ...	10	18	0
B (Bisa) ...	Ps. njalensis ...	10	50	14
C (Kpeve) ...	{ Ps. njalensis ...	5	132	1
	{ Ps. citri ...	5	42	2
D (Nkawkaw) ...	{ Ps. njalensis ...	10	20	7
	{ Ps. citri ...	10	20	2
F1 (Wiasi) ...	Ps. njalensis ...	5	22	14
F2 (Bosumuoso)	Ps. njalensis ...	10	10	2
J (Bosomtwe) ...	Ps. njalensis ...	10	20	7
K (Konongo) ...	Ps. njalensis ...	5	20	12
M (Mampong)	{ Ps. njalensis ...	{ 10	8	8
	{ Ps. njalensis ...	{ 10	34	5
	{ F. virgata ...	{ 10	50	0
<i>Nigeria :</i>				
N1 (Olanla A)	Ps. njalensis ...	5	42	6
N2 (Olanla B)	Ps. njalensis ...	5	22	15
<i>Ivory Coast :</i>				
Apprompronou	Ps. njalensis ...	{ 5	38	0
		{ 5	11	5
Kongodia ...	Ps njalensis ...	{ 5	4	2
		{ 5	25	0
		{ 10	4	2

Pseudococcus citri, Risso. has proved to be an efficient vector of Strain A and has been used for several feeding-time experiments. As far as is known at present, the virus-vector-cacao relationships are much the same for all three vectors of Strain A. The virus can be taken up by the mealybug in less than four hours' feeding on an infected plant and can be transmitted to a healthy plant in less than three hours' feeding, after which the vector is no longer infective. If starved, however, the vector can remain infective for at least five hours (transmission after 12 hours' starvation of *Ps. njalensis* has been recorded for Strain M).

Ps. njalensis has been found capable of transmitting all the strains tested, but with variable efficiency. As shown in Table 5, low and high rates of transmission may be obtained with the same species of vector, the same virus strain, and the same technique, which strongly suggests that "active" and "non-active" races of mealybugs occur; work is in progress on this subject.

Vector experiments have been facilitated by the use of cacao beans instead of seedlings as test-plants. Block watch-glasses are convenient "cages" for the mealybugs while feeding on the beans, and if transmission has occurred, symptoms appear on the first or second flush of leaves developed after germination (Posnette, A. F. "Nature," April 12, 1947).

THE COCCOIDEA ATTACKING CACAO.

Investigations have been carried out along two main lines—the biology of the known vectors of the cacao viruses, and the collection of coccid material from cacao and other plants in order to increase our knowledge of the range of the group in West Africa.

THE BIOLOGY OF THE VIRUS VECTORS.

Pseudococcus njalensis, Laing.

This species undergoes three moults before becoming adult. After the last moult, it may survive for 20-30 days before producing eggs, and for ten days after oviposition. The eggs hatch immediately, or very shortly after being extruded, the first instar larvæ usually feeding for the first time within three hours of birth. The average period from birth to egg laying is 41 days.

The males, which do not feed, survive for a few hours to two days only. Copulation has not been observed, and it must be inferred at present that reproduction is largely parthenogenetic. If, however, males are excluded from females the parthenogenetic capacity of the females decreases rapidly after three generations.

The species is formicophilic and negatively phototrophic. All stages will make conspicuous efforts to find a dark feeding station if exposed to the light. Over 30 different species of ants have been taken "attending" colonies in the field, though most of these ants are not obligatory Coccidophiles, and in some cases are actively predaceous on the larval mealybugs.

Ps. njalensis has been taken from over 100 species of introduced and indigenous plants, though its true host preferences would seem to be limited to a relatively few species—including *T. cacao*, *Desplatzia dewevrei*, *Artocarpus incisus*, *Canthium glabriflorum* and *Cola chlamydantha*.

The species, being found in the field invariably under carton ant tents, or deep in cracks in the bark of the host plants, is not heavily parasitized. Four parasites have been bred to date: A small red Cecidomyid fly that sometimes parasitizes as many as 16 per cent. of the adults in a colony; and three small wasps, one of which has been taken parasitizing ten per cent. of the adults on a pod colony. In addition, a Coccinellid beetle larva is an extremely common predator, staphylinid beetles and lepidopterous larvæ being less common. The main restricting factor in the species would seem to be climatic. The Pseudococcid mealybugs are pests in their own right essentially in dry regions. The Eastern Province of the Gold Coast has a humid climate with at least three inches of rain in ten out of twelve months in the year. These heavy downpours often wipe out a growing colony in a few hours, and it is probably for this reason that, were it not a virus vector, *Ps. njalensis* would be regarded only as a very minor pest.

With populations of the order of 40,000 per acre (at 600 trees to the acre) mostly as scattered small colonies in the canopy layer, control by chemicals would seem to be out of the question.

Ps. njalensis is disseminated in a number of different ways—the young larvæ are carried about in wind currents; all stages can move freely, and the most obvious explanation of radial spread of the swollen-shoot virus is the movement of vectors from an infected tree on to a shoot or leaf of a neighbouring healthy tree whose branches are interlocking with those of the diseased tree; the species can survive for long periods on pods that have been harvested and are being carried from one region to another for use as seed; and lastly, certain of the ant species play a small part in dispersal by carrying the mealybugs among the cacao trees or litter.

Mature adults can survive for more than ten days without food, third instar nymphs and young adults for four days, and crawlers for not more than two days. This information restricts considerably the long distance spread of young larvæ in upper air currents.

Work in hand includes investigations into movement in the field, population fluctuations, parasitism, and alternative food plants. The original life cycle figures are being checked.

Pseudococcus citri, Risso.

This species is worldwide in distribution and its life history has been studied in detail by several workers (e.g., Quayle, "Insects of Citrus and other sub-tropical fruits," Ithaca, N.Y., U.S.A., 1938).

Ps. citri is usually found associated with ants, 21 species having so far been taken "attending" it in the field. This association is not

so invariable as in *Ps. njalensis*, *Ps. citri* being quite frequently taken free of attendants.

The species has been taken from over 60 species of food plants in the Gold Coast—though not yet from Citrus. No heavy degree of infestation has been seen with the exception of a few large colonies on cacao pods. *Ps. citri* is much less common than *Ps. njalensis* on cacao in the Eastern Province of the Gold Coast, though the reverse appears to be the case in Nigeria.

Work in hand includes investigations into movement in the field, population studies and parasitism.

Ferrisia virgata, Ckll.

This species is also worldwide in distribution, and its morphology has been adequately covered (Green, "The Coccidæ of Ceylon", Vol. 5, London, 1922). The life cycle in West Africa lasts about 44 days, the egg state lasting one day, and the nymphal life three to four weeks. The young larvæ of this species are commonly windborne, and are well adapted for this type of dispersal. On no occasion has the species been taken in the field being certainly attended by ants. *F. virgata* has been taken from nearly 50 species of host plants in the Gold Coast, the heaviest infestation being on *Acalypha* sp., *Leucaena glauca*, *Viola* sp. and *Portulaca* sp. The species is by no means common on cacao, and is only rarely found in "bush" cacao farms. It is probably of negligible importance as a local virus vector, but may be important in relation to isolated outbreaks of the virus.

Work in hand includes population studies and parasitism.

THE COCCID COLLECTION.

Some 50 species of Coccoidea have been recorded from cacao in the West African Zone. Ten are new to science, five of which have recently been described by A. H. Strickland.

In addition to the collections from cacao, advantage has been taken of the areas cleared on the Square Mile to investigate the coccid fauna at the tops of tall forest trees. In this manner much information as to alternative food plants of the cacao-feeding species has been obtained, as well as information on the food plants of non-cacao species that are of some importance as pests of other crops. It is proposed to continue collecting coccid material from as wide a source as possible in view of the fact that the results are bound to be of general agricultural importance, even if not of immediate importance to cacao.

CONTROL.

Tafo Station.

Monthly inspection and destruction of virus diseased trees on the 60 acres of the old station have continued. Table 6 shows the number of outbreaks and trees cut out.

TABLE 6.
OUTBREAKS OF SWOLLEN-SHOOT ON THE OLD STATION.

Month.	New outbreaks.	Trees destroyed.		Total.
		New outbreaks.	Old outbreaks.	
April, 1946	12	18	25	43
May	11	15	12	27
June	2	2	23	25
July	3	4	6	10
August	4	8	11	19
September	1	1	15	16
October	7	8	15	23
November	7	8	23	31
December	8	11	7	18
January, 1947	5	5	11	16
February	3	3	9	12
March	6	9	17	26
Total 1946-47	69	92	174	266
„ 1945-46	40	56	160	216
„ 1944-45	47	53	117	170
„ 1943-44	44	62	74	136

It will be noticed that the number of new outbreaks, though mostly consisting of single trees, has increased over the previous years. No satisfactory explanation for the increase can be given. It had been confidently hoped that the removal of diseased trees in 1945 and 1946 from the contiguous new acquisition would have reduced the incidence of fresh outbreaks on the station. For the first time on Tafo station plants less than seven years old—there were two such—became infected.

On the One Square Mile acquisition the first cutting out of diseased trees and contacts has been completed. Two areas were, however, left untreated. On one of these pollarding experiments, and, on the other, rate of spread experiments are in progress.

Table 7 shows the number of trees destroyed and the acreage of cacao which remains in the new acquisition.

TABLE 7.
CACAO CUT OUT ON THE NEW ACQUISITION, 1946/47.

Cacao before swollen-shoot treatment (acres)	538.7
Cacao cut out in first treatment (No. of trees)	128,278
Cacao cut out in first treatment (acres) ...	172.4
Cacao standing on 1st August (acres) ...	366.3
Cut out August-March (No. of trees) ...	10,302
Cut out August-March (acres) ...	10.6
Cacao destroyed on land required for experiments (acres) ...	29.8
Standing cacao 1st April, 1947 (acres) ...	325.9
Diseased cacao required for experiments (acres) ...	26.8

Re-inspections have shown marked reductions in the number of newly diseased trees the occurrence of which is widely scattered.

Koransang.

At this station further heavy infection has taken place among the mature trees. Table 8 shows the number of trees cut out.

TABLE 8.
CACAO CUT OUT ON 20 ACRES—KORANSANG.

Period.	Trees cut out.
1944-45	2,818
1945-46	898
1946-47	631

The 1944/45 figures include those cut out at the first treatment; subsequent cutting out was the result of re-inspection. The 20 acres of this station are surrounded by heavily infected cacao farms.

III. CAPSID RESEARCH.

SUMMARY.

The capsids attacking cacao in West Africa are *Sahlbergella singularis*, Hagl., *Distantiella theobroma*, Dist., *Bryocoropsis laticollis*, Schum., and *Helopeltis* spp.

B. laticollis and *Helopeltis* normally feed on cacao pods and not on vegetative parts and the damage is not of great economic importance. *S. singularis* and *D. theobroma* feed on pods, branches and chupons causing considerable damage.

The life histories of *S. singularis* and *D. theobroma* are similar and investigations have confirmed previous work; incubation period 16-18 days, nymphal life of five instars an average of 23 days, adult life an average of 28 days during which feeding also takes place.

The primary damage is due to the collapse of tissues around the feeding punctures and can account for the death of soft shoots. On hard shoots feeding punctures alone are rarely sufficient to cause death, but invasion by fungi, of which *Calonectria rigidiuscula* (Berk et Br.), Sacc. is frequently present, commonly causes extensive die-back.

Populations of capsids have been found to fluctuate widely and normally reach a peak towards the end of the year followed by a rapid decline in January. No direct correlation between capsid numbers and climatic factors has been found but there is evidence that numbers are mainly influenced by available food supply and suitable cacao growths in which to oviposit.

Even at peak population periods the number of capsids per acre is astonishingly small. On a young tree four or five *S. singularis* or

D. theobroma nymphs can cause great damage. Feeding normally takes place at night; in the heat of the day nymphs shelter in leaf axils, stem junctions or under pods.

In the field, damage may either be of a temporary nature spread over several acres, and conveniently termed "Blast" or continuously present and confined to a small area known as a "capsid pocket." No difference between the soils of these "capsid pockets" and those of surrounding healthy cacao has been observed. "Capsid pockets" have been induced by pollarding healthy cacao, the sucker growth subsequent to pollarding being ideal for oviposition and feeding.

A number of alternative hosts of *S. singularis* is known but none seems as attractive as cacao on which this capsid has been found from Sierra Leone to the Congo.

D. theobroma has not been found on cacao in Sierra Leone, nor the French Cameroons though noted as feeding on *Ceiba pentandra* in both these territories. This species has not yet been found in the Congo.

B. laticollis oviposits and feeds on cacao pods in the Gold Coast but has not been recorded on cacao in Nigeria though observed on *Uvariadendron* spp. in close proximity to cacao.

It appears that these capsids are in various stages of changing from their indigenous host plants to cacao.

S. singularis is parasitized by *Euphorus sahlbergellæ*, Wilk., which in turn is parasitized by *Mesochorus melanothorax*, Wilk., but the degree of parasitism is not sufficient effectively to control this capsid. No parasites of *D. theobroma* have been found nor have egg parasites of either of these capsids been recorded. Predators account for the destruction of a proportion of nymphs, and ants of the genus *Macromischoides* protect cacao trees from capsid infestation. Unfortunately attempts artificially to colonize trees with these ants have failed.

Hand picking has not proved a successful control because first and second instar nymphs are difficult to find.

Good protection of young trees has been obtained by spraying with nicotine sulphate but this method of control is wasteful of insecticide, expensive and has frequently to be repeated. Hand-operated spraying machines were found to be inefficient and there is an acute shortage of nicotine.

Promising results have been obtained by painting with emulsions of D.D.T. those portions of young trees where capsid nymphs are known to shelter. The residual toxicity of this insecticide to capsid nymphs has been shown to last up to five months.

POPULATION STUDIES.

The year has been remarkable for the great disparity between the abundance of *S. singularis* in the Gold Coast and Nigeria. The numbers in the Gold Coast became almost negligible in July, a time

when in Nigeria the numbers were approaching their maximum. This disparity is almost certainly due to the small mid-crop around Tafo and the large mid-crop around Owena which enabled the capsid to increase rapidly and early in the season.

The very low numbers of *S. singularis* even at their peak hampered much of the experimental work and several investigations had to be temporarily discontinued.

Routine Collections.

The results of the routine daily collection at Tafo and Owena showed the same general tendencies as those of previous years but differed to a certain extent in detail.

At Tafo the population of *Sahlbergella* on pods and on the vegetative parts of the tree was negligible—below one capsid per 100 trees—from May to August. On pods, the population rose during September to a peak in November followed by a rapid fall to negligible numbers from January to March, 1947. The increase in the populations on the vegetative parts was much slower but was sustained until a peak was reached in January, followed by a fall to low numbers in March. The peak numbers, nine capsids per 100 trees for pod populations and 12 capsids per 100 trees for populations on the vegetative parts, were far below those of previous years, which in 1945-46 were nearly 70 capsids per 100 trees for both populations.

At Owena, the presence of a large mid-crop in 1946 allowed an early and rapid increase of pod populations of *S. singularis* to a high peak in August of 80 capsids per 100 trees. The numbers then fell rapidly from over 70 in September to under two capsids per 100 trees in December, at which low level they have remained. Vegetative populations rose far more slowly than the pod populations to a peak of 16 capsids per 100 trees, followed by a fall to low numbers for the rest of the year. It is probable that the peak was artificial as the fall in numbers coincided with a period when the farmers removed the basal chupons from their trees. Most of the capsids classified as being on the vegetative parts are found on these chupons.

Populations of *D. theobroma* on seedlings showed no notable change during the year. Numbers were at a low level throughout although there was an increase during December and January. There is at present very little suitable seedling material in the farms around Tafo station.

It is interesting to note that *D. theobroma* populations on pods follow the fluctuations of those of *S. singularis* on pods most consistently though to a lesser degree. As *S. singularis* is regularly parasitized by *Euphorus sahlbergellae*, Wilk., it seems evident therefore that this parasite has little controlling effect. In accord with this observation is the fact that the extremely rapid rise of pod populations of *Sahlbergella* at Owena started and continued when parasitism was around 40 per cent., the highest ever recorded either at Tafo or Owena.

TABLE 9.

SAHLBERGELLA SINGULARIS POPULATIONS.

A=Capsids per 100 pods.

B=Capsids per 100 trees (foliage collections).

C=Total capsids collected (on pods and foliage) per 100 trees.

	TAFO.			OWENA.		
	A	B	C	A	B	C
April, 1946 ...	6.0	3.1	14.2	1.5	2.5	8.0
May ...	1.0	0.6	0.7	4.2	2.0	23.3
June ...	0.4	0.3	0.4	6.5	5.2	52.9
July ...	0.1	0.1	0.2	6.9	7.5	48.1
August ...	0.1	0.5	0.8	14.9	16.3	96.7
September ...	1.0	0.8	4.4	14.7	13.9	84.8
October ...	2.4	3.5	12.4	11.4	3.8	33.8
November ...	4.4	4.2	13.5	5.5	3.2	12.2
December ...	15.4	5.1	9.9	2.0	5.2	6.8
January, 1947 ...	20.6	12.4	13.2	5.1	4.0	5.6
February ...	0.8	3.5	3.5	7.2	5.3	9.0
March ...	2.5	1.4	1.6	5.1	3.4	7.0

Observation Plots, Tafo.

At Tafo, six observation plots have been started during the year. Each plot contains about 200 trees and records are kept of the capsids on the individual trees together with details of the stage of development of the insects and their distribution over the tree. Discrimination is made between those found on pods, chupons and fan-branches. These individual tree records are supplemented at regular intervals by notes on the number and size of pods and the degree of flushing on the trees. To overcome the difficulty experienced in the routine collections where no record can be obtained of capsids over hands reach, long ladders are employed by the observers to search the canopy. There are two types of plot, known respectively as the Intensive and Extensive Observation Plots. When populations are low, individual trees of the Intensive Observation Plots can be examined every day but when the number of capsids is high the trees are examined on alternate days. These frequent observations enable the development of every colony of nymphs to be followed from the time of hatching. Other data such as nymphal mortality and migratory tendencies are also recorded.

Adult insects are marked at intervals and their movements about the plot are noted.

The Extensive Observation Plots are examined fortnightly. This does not give such detail as the examinations described above, but the level trend of the capsid population and distribution over the different parts of the tree are well demonstrated.

Intensive Observation Plot.

The general population figure agreed well with that obtained from the routine collections.

Starting and remaining low from May until September, the *S. singularis* population reached its maximum in December and fell off in January and subsequent months. *D. theobroma* started to increase at the same time as *S. singularis* but did not reach a peak until January when there were twice as many *D. theobroma* (387) in the plot as there were *S. singularis* (185) at its peak population.

One of the more interesting observations made was the manner in which alterations in populations appeared to be effected.

In both species an increase in numbers seems to be brought about in two ways—

- (i) an increase in the quantity of trees affected;
- (ii) a simultaneous increase in capsids per tree.

A fall in numbers seems due to a decrease in the number of capsids per tree rather than to a decrease in the number of affected trees.

The figures for *D. theobroma* for December (a month of rising population) and for March (a month of falling population) bear this out.

TABLE 10.

Month.	Trees having one or two capsids.	Trees having eight or more.
March, 1947 ...	17	12
December, 1946 ...	26	2

This thinning out of the population was even more strikingly shown by *S. singularis*. The population curve rising from June to December was followed closely by the curve of the number of affected trees. The initial slight fall of the population in January was accompanied by an increase in the number of affected trees:—

December, 1946—185 capsid observed on 48 trees.

January, 1947—174 capsids observed on 60 trees.

Thus in the falling population a given number of *S. singularis* was spread over a larger number of trees than the same number during the period of increase, viz. :—

October, 1946 : 130 *S. singularis* on 32 trees.

February, 1947 : 132 *S. singularis* on 52 trees.

This spreading of the population at the end of the peak period raises the problem of why the bugs fail to establish and maintain themselves on all but a few trees.

Field observation in the past has strongly indicated that food-supply is the main factor in regulating population fluctuations and

that pods and chupon-growth form the most acceptable food supply. Since, during periods of low populations, there are few pods and chupon regeneration is scanty on healthy trees, the capsids are maintained on the few damaged trees which are producing chupons.

The distribution of the capsids on the Intensive Plot is in accordance with this view but it is given greater support by the observations from the Extensive Plots.

Extensive Observation Plots.

These are five in number and though all have been under observation for only a short time several facts are already apparent.

The population records over the four months (December, 1946 to March, 1947) have been quite normal with a peak for both species in January. At this time the capsid population on the few pods was relatively unimportant comprising about 4 per cent. of the whole. The comparison of interest is that between populations on chupons and populations on fan-branches.

TABLE 11.

Month.	<i>S. singularis.</i>		<i>D. theobroma.</i>	
	Chupon.	Fan.	Chupon.	Fan.
January	127	36	34	6
February	26	17	5	3

All figures are for capsids per 100 trees.

The period so far covered is not one of minimum populations so that the comparative distribution at such time is uncertain. Nevertheless it does seem certain that the amplitude of the population fluctuations on vegetative parts is governed by the capsid population on the chupons.

Observation Plots, Owena.

One Intensive Observation Plot has been in operation at Owena but unfortunately the owner of the farm on which one half of the plot was situated refused to allow observations to continue so that re-organization was necessary.

Three Extensive Observation Plots have been laid out and observations will start immediately.

Owing to the re-organization required in the Intensive Observation Plot and to the desirability of having comparative data from the two types, it is not proposed to give any analysis of the observations in this report. It can, however, be mentioned that the observations from Nigeria agree broadly with those from the Gold Coast.

CAPSID POCKETS.

Initiation of capsid pockets.

This experiment was started to see if "artificial" capsid pockets could be started in healthy undamaged cacao and to follow the course of events, such as capsid population changes, in these pockets. Field observations indicated that capsid pockets were likely to be caused by two main agencies; by the breaking of the canopy caused by the falling of a large forest tree or by the breaking of the canopy due to the damage caused by chance aggregations of capsids.

The first agency was simulated by pollarding at about six feet from the ground. Three small plots of some 30 trees each have been pollarded. One plot is in 12-15 year old cacao and certain of the lower fan branches were left when pollarding; another is in cacao of over 20 years of age with a good canopy; the last is in cacao of similar age but with thinner canopy and not so healthy although still undamaged by capsids. The chupons growing after pollarding proved attractive to both *D. theobroma* and to *Sahlbergella* and large populations were built up. *S. singularis* was dominant in the first and last mentioned plots while *D. theobroma* was dominant in the 20 year old cacao which had a good canopy. The density of population seemed to depend on the number and size of chupons available. Thus the plot of young cacao showed the best regrowth and provided the highest capsid population. The plot of older cacao with the thin canopy showed poor regrowth and a smaller population developed there. Perhaps the most interesting phenomenon was the lack of damage on the cacao surrounding the pollarding plots despite the large number of capsids present within the plot.

The second treatment was the artificial colonization of the trees in two small plots. Capsids were not plentiful when the trees were being colonized, and the period over which they were colonized was sufficiently protracted to allow the trees to respond to the damage first caused and to put forth new chupon growth. Thus it is not possible to say whether the capsids could have maintained themselves without the new flush shoots. As it is, a population of capsids, almost entirely *S. singularis*, has been maintained after the initial infestation. This population is larger than in two nearby control plots. Chupons regeneration has been slower and less vigorous than in the pollarded plots and the number of capsids maintained has been smaller.

Regeneration of Capsid Pockets.

This experiment, designed to give information on the role of capsids and the fungus, *Calonectria rigidiuscula*, in maintaining a capsid pocket (chronic die-back), has made progress in the coppicing treatment but shortage of suitable insecticide has held up the spraying of the canopy branches of damaged trees. We cannot say, therefore, whether the deteriorated trees in a pocket would regenerate and maintain a healthy canopy, despite the presence of *C. rigidiuscula*, if capsids were kept away.

General observations on the sequence of events in this pocket and two other pockets not in the experiment during the year seem to indicate that *C. rigidiuscula* and capsids are both involved in the maintenance of a capsid pocket. Branches once damaged by capsids and subsequently infected by this fungus regenerate weakly.

These weak growths are very susceptible to capsid damage while still green. Many instances of a single lesion killing one of these young shoots have been noted. Thus a very small resident or a larger intermittent capsid population can cause damage out of all proportion to the numbers present. The poor growth made by damaged trees makes it unlikely that the regeneration of the canopy by capsid control measures has any economic significance when compared with the vigorous growth made after coppicing. If this supposition is correct the problems of control of both *D. theobroma* and *S. singularis* become similar and amenable to the same technique.

There are two treatments in which the deteriorated trees are coppiced to remove wood infected with *C. rigidiuscula*. The first is coppicing with spraying to eliminate capsids, the second coppicing without spraying. Ample experience has now been obtained to show that capsids can prevent the successful regeneration of coppiced cacao. The young chupons arising from the stump provide a most suitable breeding ground. Protection from capsids in the other treatment has been obtained successfully by painting with D.D.T. emulsion and the rate of growth of the chupons has been satisfactory.

ALTERNATIVE HOSTS.

Sahlbergella singularis.

At Owena, whenever sufficient capsids have become available, efforts have been made to carry out life-cycle studies on several of the recorded alternative host-plants.

Table 12 gives the life history records of *S. singularis* obtained during the past year.

TABLE 12.

S. SINGULARIS : LIFE HISTORY IN DAYS.

Name of plant.	Incubation period average.	INSTARS.					Life-cycle.
		1st.	2nd.	3rd.	4th.	5th.	
<i>Cola togoensis</i> ...	19	5	5.4	5.4	7	7.8	46
<i>Cola cordifolia</i> ...	17.4	4.6	3.6	3.6	5	8	42
<i>Ceiba pentandra</i>	19	4.8	5.9	6.1	7.3	7.7	47
<i>Theobroma cacao</i>	16.7	4.2	4.0	4.4	4.9	6.9	41

It will be seen that only the life-cycle on *Cola cordifolia* is very close to that on cacao. No difficulty is experienced in getting eggs to hatch on any of the species of trees recorded in Table 12.

A great deal of discussion has taken place as to the relationship of *S. singularis* and *Ceiba pentandra* and, although this plant has been recorded as a host in the Congo, it is only during the year under review that *S. singularis* has been taken on a *Ceiba* in a wild state in the Gold Coast. Several specimens, both adults and nymphs, were found on the water-shoots arising from the stump of a felled *Ceiba* at Tafo. The presence of nymphs and adults indicates that both egg-laying and growth to maturity took place on these shoots.

Distantiella theobroma.

This species is commonly found on *Ceiba* and it has been suggested that it has migrated from the drier north. A brief search in the Northern Territories of the Gold Coast has failed to lend support to this supposition. In spite of the many commercial "Kapok" trees found there neither capsids nor damage were seen.

Bryocoropsis laticollis.

Although this capsid has been regularly observed at Owena in all stages on *Uvariadendron* spp. during the year, no record of it on cacao in Nigeria has yet been obtained.

RESISTANT VARIETIES.

Preference tests.

A sufficient number of rooted cuttings of the supposedly capsid resistant selection, S.C.1, became available during the latter part of the year to carry out a preference test between it and similar rooted cuttings of ordinary type, T.F.7. Earlier attempts to carry out preference tests had indicated that uniformity of material as to size, succulence and type of growth (fan or chupon) was particularly important. Considerable attention was paid to this point in selecting the cuttings.

The technique of the experiment was to randomize six groups of three cuttings of S.C.1 with six similar groups of T.F.7 in an insectary. Each cutting was colonized with a single active adult collected from the field. A test was made to show that each adult could fly and thus move from plant to plant as it wished.

Twice each morning until no more were seen, the number of adults on each plant was counted. The number of new lesions was counted once each morning. It was not found possible to count the number of eggs laid each day as they were difficult to find, so oviposition was gauged by the number of emerging nymphs. It was considered that the records of frequency on each plant would show general "habitat" preferences and, together with number of lesions, food preferences. The number of lesions alone would indicate susceptibility to damage rather than a direct food preference as it cannot be assumed that rate of production of lesions is dependent on attractability of the food.

With the number of cuttings available it has only been possible to carry out a single test using adults of *Sahlbergella singularis*. The damage caused by the feeding of the capsids necessitates replacement of many of the plants after each test and a rest period to allow others to recuperate. The results of the test are shown below as final totals :—

				S.C.1.	T.F.7.
Frequency of observations	...	...	...	109	70
Number of lesions ...	...	...	...	101	100
Number of nymphs	...	...	...	18	28

The plant to plant variation in results is such that none of the differences is significant and it appears that under the conditions of the experiment S.C.1 shows neither resistance nor tolerance to *S. singularis*. Field resistance depends on many factors, such as fungus resistance and natural type of growth, which were not under trial.

BIOLOGICAL CONTROL.

The dissection of *S. singularis* nymphs was continued at Tafo and at Owena until September and October, 1946 respectively. The most outstanding feature was the high rate of parasitism found in the dissections at Owena. The highest recorded percentage since this investigation was started occurred during the month of August, 1946, when 42.4 per cent. (286 *E. sahlbergellae* in 675 *S. singularis* dissected) of the nymphs were parasitized by *Euphorus sahlbergellae*, Wilk.

Hyperparasitism of this latter insect by *Mesochorus melanathorax*, Wilk. also reached a high peak of 38 per cent. in October.

By reference to Table 13 it will be seen that this maximum parasitism coincides with the maximum *S. singularis* population at Owena which, incidentally, is also the highest population which has been recorded from either station since the routine collections were started.

TABLE 13.

PERCENTAGE PARASITISM OF *S. SINGULARIS* AND
PERCENTAGE HYPERPARASITISM OF *E. SAHLBERGELLAE*.

Month.	TAFO.	OWENA.	
	% Parasitism.	% Parasitism.	% Hyperparasitism.
April, 1946 ...	25.1	36.8	—
May ...	17.2	36.7	8.1
June ...	11.5	37.3	7.5
July ...	9.9	36.1	5.7
August ...	5.9	42.4	14.0
September ...	5.3	24.8	28.2
October ...	—	21.2	38.3

The high rate of parasitism at Owen did not prevent the numbers of *S. singularis* rising rapidly to this high maximum.

Egg parasites.

No egg parasites have been found during the year. A considerable amount of time and energy has been devoted to the search for egg parasites of both *S. singularis* and *D. theobroma* and it seems likely that none exists.

Exploratory work in other countries.

One of the entomologists spent one and a half months in the cacao-growing districts of the Belgian Congo in a search for parasites other than *E. sahlbergellae*. *S. singularis* was present in fair numbers on cacao of all ages, in all the districts visited. *D. theobroma* was not found.

Dissection of a large number of *S. singularis* nymphs demonstrated the presence of a euphorine parasite; a maximum of 30 per cent. of the nymphs were found parasitized. This parasite was in all probability *E. sahlbergellae* but no adults were obtained for determination.

There seems little point in continuing the search for other parasites of *S. singularis* in the Congo cacao areas. There are, however, several lacunae in our knowledge of the Congo cacao and its insect pests, and the possibility of obtaining a parasite from some of the related *Sahlbergella* species recorded from the Congo must still remain an open one. The Congo is relatively rich in Bryocorine capsids, at least four species of the genus *Sahlbergella* having been recorded.

Macromischoides investigations.

During April and May, 1946, the early part of the wet season, numerous incipient *Macromischoides* colonies each formed by a single queen with eggs and larvæ, were found on many trees and shrubs including cacao. The transfer of these nests offered new possibilities of improving natural dispersal to protect cacao trees from capsids. Unfortunately, not one out of over 50 transfers has been successful. This was partly due to the heavy leaf fall and consequent loss of nests during the unusually prolonged middle dry season but was mainly due to the ravages of other species of ant.

The growth of the *Milletia* (previously called *Lonchocarpus*) in the Rejuvenation Trial has been poor and the area has now been given over to D.D.T. control experiments. A second experiment in which *Milletia* is used as a shade tree in establishing cacao, has been laid out in the Square Mile. The *Milletia* was planted in 1946 and has made variable, though on the whole, good growth. The cacao is being planted in 1947 so that the *Milletia* should be large enough to harbour *Macromischoides* by the time the cacao reaches a capsid-susceptible stage.

The effectiveness of the protection given by *Macromischoides* has recently been illustrated by the severe damage suffered by some trees in the First Progeny Trial which once harboured but later lost the ant.

CHEMICAL CONTROL.

In 1944 small supplies of the new synthetic insecticide D.D.T. became available and preliminary experiments showed that this chemical had distinct possibilities as a controlling agent against *S. singularis* and *D. theobroma*. This early work was done using a 1 per cent. solution of D.D.T. in a vegetable oil and water emulsion. Both species were killed and a residual toxicity up to 15 days was apparent.

As with all machine-spraying methods the wastage of spray on the leaves and past the plant made this method costly and a second series of laboratory experiments was started to investigate the possibilities of applying higher concentrations only on the woody tissues which are attacked by the capsids. It was presumed that the higher concentrations would give a longer residual action and the economy in application would counterbalance the increased cost of the more concentrated solutions.

Preliminary experiments.

Five treatments were first tried out to observe their toxicity to cacao plants:—

- (a) 2·5 per cent. D.D.T. in a Xylene emulsion—slight browning on flush stems and young flush leaves. On older tissue, no perceptible damage was found.
- (b) Saturated solution of D.D.T. in petrol (approximately 8 per cent.) produced immediate serious damage to flush tissue. Considerable bark split and damage appeared later on older tissue.
- (c) 5 per cent. in kerosene—immediate damage to young tissue and death of all painted parts later.
- (d) D.D.T. in vegetable oils—general deterioration and poor growth later.
- (e) D.D.T. pastes in talc or lime—no damage but sticking properties poor.

It was decided only to continue the use of the 2·5 per cent. Xylene emulsion. The concentrated solution was 25 per cent. D.D.T. in Xylene with an emulsifier which readily made an excellent stable emulsion on the addition of water.

Sixteen plants were placed in four rows of four each, two of the rows acting as controls. The eight treated plants were painted with the 2·5 per cent. emulsion and left under tree shade. At intervals active fifth instar *D. theobroma* nymphs were caged on the treated and control plants and observed. Table 14 gives the results obtained.

TABLE 14.

Time from treatment.		7 weeks.	12 weeks.	18 weeks.	24 weeks.
Number of capsids used		8	8	8	16
Average life of test insect in days	Treated Control	1.9 3.5*	4.0 5.0*	4.3 6.6*	3.6 8.3*

* One or more of the living bugs had to be removed to save the plant for further experiments.

Small scale field experiment.

Twelve 1/16-acre plots each containing about 135 seedling trees which, in the past, had been very badly damaged by capsids were made available for testing this method of treatment.

The trees, in six plots selected at random, were treated with the 2.5 per cent. Xylene emulsion, the trees in the other six plots being left as controls.

As it is a normal habit of the capsids in their later instars to seek shelter in branch unions and forks during the heat of the day it was decided to paint some of the plots only at these points. If this method were successful a great economy of insecticide would be achieved. The trees in the other plots were painted over most of the woody tissue. The result of the partial painting whilst reasonably successful was not entirely so, as it was found that the earlier instars found sufficient shelter under leaf petioles at the tips of the twigs, and during these earlier instars damage was done which resulted in considerable die-back of the tips.

Regular counts of the number of capsids were taken on all plots. The average number of capsids seen on the treated plots, which included those partially painted, was only 11 per cent. of the total over 20 weeks' observation. At 20 weeks after painting 84 per cent. of the capsids seen were on the untreated plots.

Similar results have been obtained on other plots including those at the Akwadum sub-station.

Whilst this method shows every promise of being successful in controlling capsids on young trees, more work requires to be done on types of solution, methods of application and action on other insects before it can be advanced for general use.

Other Insecticides.

Supplies of Nicotine Sulphate 40 per cent. and a 4 per cent. Nicotine insecticide have now been obtained in small quantities and are being used where the residual action insecticides are not satisfactory.

Gammexane Smoke Bombs.

Supplies of these insecticidal smoke bombs have been received but their application out-of-doors against capsid pests has not been fully investigated. Preliminary results indicate that such methods are dependent on weather conditions.

IV. SOIL SURVEYS.

SUMMARY.

It has been shown that the incidence of virus disease or of capsid pests of cacao is in no way dependent on the differences between soils in which cacao is grown in West Africa.

A preliminary soil survey of the forest areas of the Gold Coast, Togo, Nigeria and British Cameroons has been completed. As a result of this preliminary survey the principal soils have been identified, their distribution roughly gauged and the environmental conditions under which they occur noted.

A method of detailed soil survey has been evolved. Detailed soil surveys of the Institute's station at Tafo and the sub-stations have been completed. Detailed soil surveys of the Department of Agriculture's proposed experiment station at Kumasi and those at Oyoko and Asuansi have also been completed. Soil maps of all these experiment stations have been prepared.

A method of Detailed Reconnaissance Survey has been evolved with the object of mapping the actual and potential soils suitable for cacao in West Africa. Such maps would also supply information on which can be based correct land use. The method of soil survey has been successfully tested over 800 square miles of the Densu River basin. As a result of this trial, estimates of the cost and time taken in carrying out Detailed Reconnaissance Surveys in forest country have been prepared. The trial has shown that an efficient organisation, comprising locally trained staff under the direction of trained Soil Scientists, is essential for the prosecution of such surveys. A nucleus organisation has been built and can be expanded if larger areas are to be surveyed.

Intensive investigations have been carried out on the morphology and field characteristics of soils derived from the Cape Coast Granite Complex. These soils support the largest area of cacao in the Gold Coast. The next soils most widely planted with cacao are those derived from Birrimian metamorphic rocks; these soils are now receiving intensive study.

A large collection of rocks and profile specimens of soils to which they have given rise under different conditions of relief and drainage have been collected and are available at the Institute for reference.

Definition, based on field characters, has been given to soils suitable for permanent cacao cultivation, those which may require the application of fertilizers to maintain productivity and those which, because of undesirable physical characters, are unsuited to cacao cultivation.

DETAILED RECONNAISSANCE SOIL SURVEYS: PRINCIPLES.

The soil surveys of the West African cacao-growing regions are not to be considered as ends in themselves permitting completion at some indefinite time in the future. They have a definite economic

aim: to serve as a basis for the efficient development of cacao culture. To achieve this end they require to be completed at an early date. At the present time it is desired to replant suitable soils with cacao in those areas devastated by virus diseases and to extend cacao culture over areas as yet unexploited. This serves as some indication of the immediate necessity for reliable information on soils, their distribution and their suitability as media for the profitable production of cacao. Any scheme of soil surveys devised, therefore, must take into account the necessity for completing them in rapid time.

The rapid prosecution of soil surveys can be achieved by two means: the development of speedy field techniques and the employment of a large field force. Both means are incorporated in the scheme of soil survey proposed.

The formidable problem that the prosecution of rapid soil surveys presents can be judged when it is stated that, in the Gold Coast, the area in which climatic and environmental conditions occur suitable for cacao production totals approximately 31,000 square miles and that this area is covered either by tall secondary forest or by secondary forest that has been thinned to permit the planting of subsistence crops and cacao.

Within a given climatic region the soils that occur and their distribution are determined almost wholly by the lithology, *i.e.*, the nature of the parent rocks, and by the relief and drainage.

In West Africa cacao is grown under climatic conditions which, from the point of view of soil formation can be considered more or less uniform. The topography of the greater part of the cacao-growing regions is also of a similar type throughout, consisting of a relatively well-developed peneplane. Under such conditions, where the country rock is of uniform character a regular sequence of soils is found from the summits of undulations down the slopes to the stream and river valleys at their base giving rise to a distinctive soil pattern which is repeated whenever the same type of country rock occurs. Such soil sequences and patterns first received prominent attention in tropical Africa and are characteristic of the main cacao-growing regions.

It follows that, if the topography and lithology of the cacao-growing regions are known in some detail, approximately accurate maps of soil distribution can be constructed once the soil sequences occurring over the various rock types are determined. The method of rapid soil survey developed has been based on this principle.

As far as the Gold Coast is concerned, topographical maps of the present and potential cacao-growing areas exist on a scale of one inch to the mile. These give the drainage in considerable detail whilst the relief is shown by form-lines, based on limited aneroid readings, at 50 foot intervals.

The lithological information available, however, is inadequate. The geological maps published are almost wholly chronological in character, that is they show areas underlain by systems of rocks each characterized by being of a particular geological age and not areas

where rocks of a specific type occur. Owing to the lack of sufficient knowledge of the nature of the rocks and their distribution, the major and undoubtedly the more difficult, part of the soil survey based on the principles described will consist of the production of a preliminary lithological map.

The suggested method of survey, therefore, comprises two tasks : the first, the mapping of the distribution of the parent rocks; and the second, the determination of the topographical sequence of soils over each type of parent rock. The first task it is proposed should be performed by reconnaissance methods, *i.e.*, by interpolations made from scattered observations at some distance apart. Whilst the second task should be carried out by detailed surveys of small areas representative of the topography developed over each rock type. For this reason the surveys as a whole are termed : Detailed Reconnaissance Soil Surveys.

Considerable importance is accorded the parent materials from which soils have been developed. This is due to two reasons : first, the unit of soil mapping and classification now most widely adopted, and the one used in the work now being reported on, is the *Soil Series* which comprises soils with similar profiles derived from similar materials under similar conditions of development; and secondly, because it is the nature of the parent rock which, where other soil-forming factors are uniform, determines the inherent productivity of a soil.

DETAILED RECONNAISSANCE SOIL SURVEYS : TECHNIQUES DEVISED.

Reconnaissance (Lithological) Surveys.

Since two of the main bases on which reconnaissance surveys are to be built up are relief and drainage, it was decided to carry out the field work drainage basin by drainage basin rather than by arbitrary areas, administrative or otherwise. This method of dividing up the country to be surveyed has many advantages, especially where little-developed or undeveloped territory is concerned. In determining soil boundaries one must have some permanent and easily recognizable features to which to relate them. This applies not only to the map makers but to the map users as well. In a well-settled countryside soil boundaries can most conveniently be fixed relative to cultural features such as roads and settlements, but in densely forested regions uninhabited or only very sparsely populated, roads may be entirely lacking and villages and trails very few and far between. Under such conditions the easiest method of locating anything is by reference to the relief and drainage, more particularly the latter.

After the Preliminary Soil Survey had been completed, and after a careful study of the geological and topographical maps, the cacao-producing areas of West Africa were divided into a number of provisional natural regions based on river drainage basins. In the Gold Coast ten major regions of this nature have been recognized,

though for the purposes of field work most of them would be subdivided.

Prior to commencing the lithological survey of any particular region or sub-region, the soil scientist-in-charge would first assemble and digest all the available information on its relief, drainage, geology and culture and then carry out a rapid reconnaissance to determine the main rock types occurring, and the earths to which they give rise. On the basis of this information the manner in which the region will be covered is decided upon and the sites which the mobile field base will successively occupy and from which surveyors will work would be determined.

The actual survey for determining the nature of the rocks forming the parent materials of the soils and for mapping their distribution would be carried out as follows:—Field parties consisting of two assistants are sent out with appropriate portions of the topographical maps of the region and instructed to traverse all, or certain, of the trails indicated on the maps within the area to which they are allotted. In every ten chains (one furlong) they would collect a representative rock sample, mark the site where it was found on their maps, and bring the samples to the field base for identification. Where rocks do not occur the field parties would bring in a sub-soil sample taken as deeply as practicable, *i.e.*, from three to three and a half feet in depth, for, with experience, it is possible to infer the parent rock from the nature of the material to which it gives rise on weathering.

In regions where trails are absent or very few, it would be necessary to resort to compass traverses. In such work a team consisting of a direction-giver with a compass, a distance-measurer with a Gunter's chain, a topography recorder, and two rock and soil collectors would be used. They would be supplied with a suitable number of labourers to assist in cutting lines and in using the chain. Traverses would be run from a convenient base line such as a road, trail, river, etc., or from a line specially cut for this purpose through the bush.

At the field base, a thoroughly trained assistant with the aid of reference specimens would identify the rock and soil samples brought in and a cartographer would plot this information on previously prepared maps.

As sectional maps are completed at the field base they would be forwarded to the main base and from them the soil scientists-in-charge would construct the lithological map.

Apart from the scientific principles involved, two practical considerations also enter into the method of soil survey proposed. One of these considerations, the extensive area to be surveyed and the necessity of employing rapid methods if the work is to be completed in time has already been pointed out. The other practical consideration concerns the assistance available for soil surveys. Owing to the large area needed to be covered and the limited time the surveys must take, a considerable number of assistants would be required. The

employment of an adequate number of trained European soil men would be economically impossible even were they available, which they are not. This means that locally recruited African staff with no previous experience of soil work would have to be utilized for the survey. Such assistants would, in the vast majority of cases, have received little or no previous scientific training whatsoever. For these reasons the work that the field staff would have to perform must obviously be as simple as possible. The collection of rocks and sub-soil samples seem the simplest and most straightforward tasks that it was possible to ask an unqualified operative to perform and it was this consideration which, to a very large degree, led to the elaboration of the method of detailed reconnaissance soil survey.

Detailed Soil Surveys.

Detailed soil surveys were designed to be carried out as follows:— After a rapid reconnaissance of the area by the soil scientist-in-charge the mappable soils occurring would be determined. A legend would then be drawn up describing the profile of each soil and the topographical site where it is found. This information, together with horizon samples of each profile, would be given to the team carrying out the survey. This team would then lay down a one-chain (66 feet) grid of cut lines over the area to be surveyed, if it was under 100 acres in size, and borings would be made with soil chisel and auger at regular intervals with reference to the grid and the soil series determined and indicated by symbols on specially prepared outline maps. At the same time drainage, rock outcrops, cultural features, etc., would be put in. When the borings are completed over the area being surveyed, a provisional soil map is prepared by interpolations between borings. The soil boundaries thus sketched in are verified, or modified if necessary, by tracing them along their course, and making additional borings where needed. The final soil map is then prepared from the corrected provisional map. Pits are sunk in areas representative of each soil series and the soil profile described in detail and sampled for record and analysis. This was the method used in the detailed soil survey of the Institute's lands described briefly in the last Annual Report (1946).

With large areas the above method would be too laborious and where one to three square miles require detailed surveying a modified procedure is adopted. In these cases, the area is divided into parallel strips one chain wide and five chains apart from centre to centre. The soil series along the strips are determined by regularly spaced borings and a provisional soil map prepared by interpolation. The soil boundaries between the strips are then verified, and modified where necessary, by offsets at right-angles to the initial strips.

In work of the above character, six to 12 assistants would be employed, together with a number of labourers for clearing and chaining. Some of the assistants would require to have had previous training in the use of survey instruments.

SOIL SURVEY OF THE DENSU BASIN.

Reconnaissance Soil (Lithological) Survey.

The Detailed Reconnaissance Soil Survey of the Upper Densu basin comprising about 800 square miles was undertaken to gain information on the practicability of the methods proposed and the cost of work of this nature.

April was spent in training recruits in the use of the prismatic compass and chain, in the methods of recording topography, vegetation, and cultural features, and in the techniques of soil and rock collection.

The actual work of surveying the Densu basin commenced in the first half of May and continued until the end of October. Progress was slow: with the staff employed, the 800 square miles should have been completed in two months instead of six. In part, this slowness can, of course, be accounted for as being due to normal difficulties in getting something new under way, but to a large extent it was due to inadequate supervision, shortage of equipment and transport difficulties.

When field work first started, the system of taking observations along trails, roads and railways was employed; but it was found that trails as recorded at the date of issue of the maps being used did not always correspond with the trails existing at the present time. Traverses along trails were, therefore, abandoned in favour of compass traverses spaced at distances of 100 chains ($1\frac{1}{4}$ miles) apart. The location of these traverses was determined after a careful study of the topography and geology of the area. The compass traverses commenced along roads, and a small team, headed by a trained topographical surveyor, marked out the starting points in advance and assisted in checking the accuracy of the bearings followed.

Five teams were finally trained for the lithological survey.

On an average, it was found possible for one team to cover about $3\frac{1}{4}$ miles per day, more being done in good cacao farms and less in abandoned farms and dense secondary bush. With the traverses 100 chains apart, this rate of progress results in five such teams covering 20 square miles a day and 100 square miles in a five-day week.

Detailed Soil Surveys.

Within the Densu basin, Detailed Soil Surveys were carried out on the Institute's extension plots at Akwadum, Adonkwanta, Nankese and Korangasang. At Korangasang, the whole farm (110 acres) belonging to C. E. Badoo and Family, previously the subject of a detailed cacao survey by W. H. Beckett was mapped. In addition to these plots, the unit cacao farms at Mangoase and at Pawtroasi were surveyed. Approximate soil maps were prepared of the abandoned vegetable gardens at Nsawam and Mangoase. Two strips across the detritus at the base of the Voltaian scarp; two strips across the flood plain of the Densu at Mangoase and one strip at the old Media

vegetable farm south of Nsawam were also mapped. The site, near Oyoko, of the proposed experiment station for the Eastern Province was surveyed in considerable detail. Previously, the Institute's lands at Tafo had been mapped.

Outside the Densu basin, soil surveys in considerable detail were executed of the proposed experiment station for Ashanti and the Western Province experiment station at Asuansi.

The execution of the detailed surveys proceeded smoothly.

Local Staff.

This is probably the first time that extensive field investigations on soils have been attempted using a large, locally recruited staff with no formal qualifications for this work.

When the scheme of soil survey described was first drawn up, particular care was taken to devise procedures capable of being carried out by locally recruited staff which would require the very minimum of knowledge regarding soils—in fact nothing more than the conscientious collection of rock and sub-soil samples. As the work progressed, however, many of the assistants employed showed, what might be expected in a country that is almost wholly agricultural, much interest in soils and, in the case of some, considerable ability for soil work. It was then found that in a few months it was possible to teach local staff with educational qualifications varying from the standard required for Primary School Leaving Certificate to that needed for the Cambridge School Leaving Certificate much of what a soil-surveyor overseas would be called upon to know. In consequence, it has been found possible to make the information collected by field parties far more elaborate than was originally planned.

As elsewhere, skilled supervision and some system of checking the work of field parties is necessary to ensure the reliability of the observations collected. Unfortunately, skilled supervision has been wholly inadequate. A considerable degree of check is, however, ensured by a consideration of the relief and drainage as shown on the one-inch maps of the Survey Department. Where inaccuracies in the work have been discovered they have occurred almost wholly from misunderstandings, and very rarely, indeed, from a lack of conscientious effort. Such sources of error are removable by the use of carefully devised routine procedures and these have been elaborated both for the reconnaissance and detailed surveys and are continually being improved upon. On large-scaled and difficult enterprises, such as surveying the soils of 31,000 square miles of humid forest country, a standard routine and precise discipline not only aid in the efficiency of the work but give the operatives confidence.

Costs.

The survey of the Densu basin has provided information regarding costs of detailed reconnaissance soil surveys under the conditions which obtain in West Africa. These costs compare favourably with those for similar work conducted in the United States of America.

SOILS OF THE UPPER DENSU BASIN.

The general disposition of the soils of this region may be briefly summarized as follows:—

By far the greater part of the basin comprises soils developed over granodiorites and granites of the Cape Coast Granite Complex. These soils derived from granitoid rocks may be divided into two groups occurring north and south respectively of a line connecting Koforidua and Suhum.

The soils of the northern group have developed from biotite and hornblende granodiorites without coarse quartz crystals (phenocrysts), what quartz occurs being mainly in the form of intergrowth in the feldspar crystals. The red, residual soils formed from these rocks are relatively heavy in texture and have a well-developed profile structure consisting of light-texture surface horizons, underlain by a gravel and ironstone concretion layer which in turn is underlain by a zone of red, orange and pale yellow mottled clay which grades into the rotten parent rock. Brownish-yellow sandy soils developed over hill-wash occupy the lower slopes of undulations and grey, waterlogged sands and clays occur in river and stream bottoms. The red upland earths of this association form excellent cacao soils, but the other components are indifferent or even poor media for cacao production.

The earths of the southern group have developed over granite or granodiorites containing varying quantities of moderately coarse, granular quartz. These rocks in many places contain numerous veins of aplite and pegmatite and inclusions of migmatite (difficultly weatherable hornblende granodiorite and gneiss derived from the granitization of basic igneous rocks such as basalts). These result in the area weathering to a rather pronouncedly undulating surface. The rounded hills have steeper slopes than the undulations further north and often owe their existence to aplite, pegmatite or migmatite cores. Where migmatite inclusions of some size occur they give rise to steep hills of massive rocks which tend to support a sparse vegetation, *e.g.*, Tetekasum hill. Mount Nyana, 1,618 feet, however, is an exception; being high enough to reach cloud level, it is well watered and supports excellent cacao in the scanty earth between boulders. It is after entering this portion of the region that the Densu flows through a small but steep gorge for some miles of its course. In consequence of this lithological structure, the sedentary earths developed over the rocks of this area are often shallow, and since they have a somewhat coarse sandy texture (or, where pegmatite veins are frequent, contain much quartz, grit and gravel) they tend to be droughty. This characteristic is accentuated by the fact that in the south the average annual rainfall approaches the minimum for successful cacao-production, *i.e.*, 45 inches. Where the granites of the southern group are free from migmatite, aplite and pegmatite inclusions and veins they weather very deeply, indeed, producing more or less uniform red, coarse sandy or gritty clays. Such earths which are patchy in their

occurrence resemble the granite earths of Kumasi and Asuansi and form good cacao soils. Cacao planted in the soils of this southern group of granites has all but entirely been killed out by virus disease, and the greater part of the area has degenerated into low bush, in places heavily farmed and producing corn and cassava. Much of the tree growth has been cut down for firewood for Accra. It is the Soil Scientist's considered opinion that over much of this area cacao would have declined and died out, sooner or later, even had it not been attacked by virus disease. Due to the combination of unsatisfactory soils, destruction of the arborescent vegetation and heavy food farming, replanting of the greater part of this portion of the Densu basin cannot be considered an economic proposition.

The watershed to the north-west of the basin consists of hills comprised of greywackes and the adjacent lower-lying areas, of greywackes and phyllites interstratified. These rocks belong to the upper series of the Birrimian System. The hills of the drainage divide, *e.g.*, Peki and Atukrom hills are steep and rocky and at present support good cacao. Good cacao also occurs at present over the lower-lying land as well. The earths formed from these rocks are heavy, somewhat "greasy" clays, red-brown on elevated sites, brown or yellow-brown on lower slopes and bluish-grey or grey and brown mottled in valleys and depressions. The moisture relationships of these soils are good, but their inherent nutrient status, judging from the character of the parent rocks, should be poor and, if this is so, cacao on these earths would need manuring for permanent production.

The boundary of the Densu basin on the north-east is formed by the Voltaian scarp consisting chiefly of coarse sand-stones with some clay shales interstratified. Detritus from this scarp covers the granite over a belt about a mile in width. The earths formed from this detrital material consist of clayey sand and sand-stone brash with no well-defined profile structure. They are probably well watered but their inherent nutrient status can be expected to be low.

On the east and south-east the drainage divide is formed by the Akwapiman ridge composed of quartzites, sand-stones and fairly strongly metamorphosed clay shales. East and south-east of Nsawam occur extensive areas of red, sandy soils derived from these rocks. They are mostly covered with low bush and grass and are much food-farmed, corn and cassava being the chief crops grown. These soils have a poor nutrient status and unsatisfactory moisture regimes and what cacao was planted on them has, in most cases, long died out.

The southern boundary is formed by secondary grassland with cassava and corn farms, covering grey and brown granite earths, which merges further south with the coastal plains and swamps which receive annual precipitations of about 30 inches, or even less.

The western divide separating the Densu drainage from the Ayensu basin is composed of granite hills containing abundant veins of pegmatite. Here, coarse gritty and gravelly earths result from the weathering of the country rocks.

Throughout the lower-lying parts of the basin occur narrow expanses of recent river alluvium. Over this two soils occur; heavy grey and brown mottled clays, usually swampy, and sandy, natural levees forming the river and stream banks. The former are one of the principal sugar cane soils of the Gold Coast; they are unsuited to good cacao growth. The latter support numerous odd crops, but it is doubtful if they are suitable for anything excepting, perhaps, coconut palms.

SOILS DEVELOPED OVER THE ROCKS OF THE CAPE COAST GRANITE COMPLEX.

With the exception of the Pawtroasi unit cacao farm, the strip at Media vegetable farm and the two strips across the detritus below the Voltaian scarp, all the detailed soil surveys have been of soils, the parent materials of which have been derived from the weathering of granite and related rocks of the Cape Coast Granite Complex. As is well known, by far the greater amount of Gold Coast cacao is grown on soils so derived. These earths have now been very thoroughly studied; their morphology is known in detail and considerable information has been gathered concerning their characteristics as media for crop-growth, particularly cacao culture; in addition, many empirical data have been gained as to the manner in which these earths behave on clearing and cultivation to subsistence crops.

CRITERIA FOR GOOD AND BAD CACAO SOILS.

Elsewhere, criteria for good and bad cacao soils have been based mainly on laboratory analyses. In the present instance, such a basis would be of little utility. First, laboratory facilities are not available as yet, and secondly, if they were, such data would not be intelligible to the large majority of the Agricultural Departments' Junior staff in contact with cacao farmers. What is needed is a field guide based on macroscopic characteristics of soils.

The establishment of the desired criteria would be a relatively simple matter were cacao yields and longevity available for the soils occurring in the areas climatically suitable for cacao culture, but since cacao production is a peasant industry such information is lacking. Using, however, the known facts about the ecology of cacao and broad, general conclusions regarding the soils on which it is successfully, or unsuccessfully, grown in West Africa, it has been possible to indicate approximately on which soils it is likely that cacao will succeed and on which planting should be avoided. These suggestions were, at the request of the Department of Agriculture incorporated in an illustrated brochure entitled "Cacao Soils—Good and Bad" issued early in the present year. Further work along these lines is proceeding.

GENERAL.

During the past year, numerous demonstrations of the activities of the Division have been given to visitors of many categories and at the end of October the soil scientist gave, on request, a broadcast talk entitled "The Soils that Support Us." The sort of work described and shown during demonstrations has won widespread appreciation not only amongst agricultural workers but amongst laymen as well. The reasons for this are twofold: First, soils have been treated as media for the growth of plants; secondly, soils have been described in terms of their field characters.

V. EXPERIMENTAL PLOTS IN NATIVE FARMS.

SUMMARY.

Five plots totalling 112·7 acres, all in various degrees of dereliction through swollen-shoot disease were taken over for the following purposes:—

To ascertain whether cacao could be successfully re-established once the infected trees were removed.

To record the ingress of swollen-shoot and capsids to the re-established cacao.

To investigate agricultural methods of re-establishment.

To ascertain whether a farm already infected with, and surrounded by swollen-shoot disease could be kept in production by cutting out diseased trees within the farm boundaries.

Results indicate that successful re-establishment is dependent on the soil. Re-establishment has proved difficult and may prove impossible on certain soils even though these once supported cacao. On other soils re-establishment has so far been very successful though initial difficulties have occurred if such soils had been food-farmed prior to replanting cacao.

The incidence of swollen-shoot disease in re-established cacao has, to date, been very small. The figures are given in Table 15.

TABLE 15.

INCIDENCE OF SWOLLEN-SHOOT DISEASE.

Experimental plots.	Planted.	Approximate number of cacao plants.	Number diseased.
Akwadum ...	1942	28,000	7
Nankese ...	1945	35,000	1
Kukua ...	1945	50,000	1
Adonkwanta ...	1945	45,000	12
Koransang ...	1945	15,000	34

Capsids have caused damage on certain areas at Akwadam, but on other areas on the farm where the cacao is in a similar stage of growth, little or no damage has occurred. The cacao plants on the other experimental farms are generally too young for capsid attack.

The incidence of other pests, notably Scolytid borers and ring-barking caterpillars, has been noted.

Statistical experiments on agronomy have not been undertaken by the Institute on these experimental plots. Operations have been designed to make conditions on the farms suitable for cacao growth. In order to safeguard soil fertility no food farming which involves soil disturbance has been undertaken. Natural regeneration of forest growths has been encouraged and where regeneration has been inadequate shade has been planted. When the cacao begins to be crowded by surrounding vegetation this is cut and used as mulch round the cacao stands.

It has been found safer to plant cacao seed at stake than to use nursery transplants; these fail to establish if a rainless period closely follows transplanting.

The experimental farms are unlikely to provide the substantial areas of uniform cacao as had been hoped; in spite of regular spacing and uniform age, soil differences have led to unevenness in growth.

On the 20 acres at Korangsang the Institute has endeavoured to save the healthy cacao trees by cutting out those diseased. There were 6,584 trees when the farm was taken over in 1944. No fewer than 2,603 diseased trees were removed at the first cutting and thereafter a further 1,774 have shown disease symptoms and have been cut out.

AKWADUM.

On the 16 acres planted with cacao sown at stake in 1942, growth has generally been satisfactory. The growth in July, August and September, 1946, caused a serious set-back and complete defoliation of a high proportion of young cacao trees; a number of supplies planted before the drought was killed. Recovery of the established plants was rapid with the advent of rain at the end of September, but a small crop on the most advanced trees was lost.

Three spacings had been adopted; 10 feet by 10 feet, 5 feet by 5 feet and, conforming to native practice, randomized. Three seeds had been planted to each stand. Judged by eye the random-planted plots, in which the cacao was closely spaced according to native practice, appear the most promising, and it has been necessary to thin certain of these plots where a cacao canopy has been formed.

Natural vegetation has been encouraged to supply side shade and soil cover. Periodically this vegetation is cut back when in contact with the cacao and the loppings are used as mulch.

There is considerable variation in the growth of cacao over the 16 acres and this is correlated with differences in soil. Outstandingly

the best cacao is growing on a small area of sandy clay which formerly supported wine palms and is constantly moist. Cacao is growing well on the red sedentary soils of the Koforidua-Nankese series which comprise about half the area of the farm. The poorest growth occurs on the pale transported sands which are subject to drought.

On certain plots capsid damage has been severe and hand picking has proved ineffective. The Division of Entomology has taken over these plots to investigate the effects of D.D.T. as a control of capsids.

Two plants with swollen-shoot disease were rogued during the year.

NANKESE.

In general the cacao, planted in 1945, has grown well during the period under review. The July-September drought accounted for the loss of a number of supplies which were replaced after the drought had broken.

The best grown cacao occurs on a low area in which numerous oil palms supply shade, the worst on land which had been heavily food-farmed before the Institute took over the station.

During the July-September drought and in January many young seedlings were killed or damaged by a small Scolytid borer. This borer has been observed causing damage in Nigeria and in the Gold Coast during periods of drought but is of negligible importance at other times of the year. Seedlings up to one year old appear particularly susceptible.

Another pest, not previously recorded by the Institute, was a large hairy caterpillar. The presence of these was noted in January and February when a number of well-grown seedlings was ring barked and killed. The caterpillars apparently feed at night and were found in the daytime concealed under the mulch surrounding the cacao. Search for them was made and a large number destroyed. They disappeared altogether in March. Unfortunately most of those kept in the laboratory died before pupating and those which did pupate failed to emerge as adults. It has therefore been impossible accurately to determine the species to which these caterpillars belong.

One well-grown seedling was found infected with swollen-shoot and was rogued; it was the first diseased seedling to have been found in the 18 acres.

KUKUA.

Very great variations in the growth of the cacao at Kukua have now become apparent. These variations are undoubtedly due in the main to the differences in soils, particularly in regard to moisture relationships. In the moister soils of the 30 acres growth has been excellent, but in the drier soils where rock approaches the surface repeated attempts have failed to establish cacao.

In parts of the farm there are numerous rain trees planted by the owner some ten years previously. The cacao has not grown well in the shade of these trees and a number has been cut out. In the other parts of the farm natural bush regeneration has been encouraged; where grass had become dominant following food farming, plantains, *Leucaena* and *Gliricidia* have been planted.

Borer attack was not as severe as in the previous year, but ring-barking caterpillars, previously mentioned under Nankese, were numerous and caused considerable damage. Over 2,300 were caught and destroyed.

In one half of the farm swollen-shoot disease and capsids are not to be controlled but their rate of spread is to be recorded; on the other half control measures will be adopted. During the year one seedling was found with swollen-shoot and was pulled up in error since it occurred in the non-controlled half.

ADONKWANTA.

As in the other stations growth of the cacao has been uneven. On the good soils not heavily food-farmed in previous years the cacao has flourished, but establishment has been difficult, and subsequent growth poor, on the pale sandy soils and on the heavily farmed good soils. During the year banana and *Gliricidia* shade has been planted in the grassy areas and conditions are now more suitable for cacao.

Loss of supplies through drought was extensive, but re-supplying was carried out in the latter part of 1946.

The station, at the request of the owner, was further extended from 26 acres to 28·7 acres the additional land supporting both swollen-shoot diseased and healthy trees. The diseased trees were cut out at once. Cacao seed was planted under the healthy cacao which, after the harvest, was cut down since infection from immediately adjacent diseased cacao off the station appeared inevitable. The cacao seedlings, subjected to the sudden change of conditions when the old trees were removed, have not grown well.

As at Kukua, the station at Adonkwanta is divided into two. On one half disease and pests are to be controlled, on the other recorded only. On the controlled half five seedlings have been noted with disease and have been rogued; on the recorded half seven seedlings have become infected and have been left. Further particulars have been given in Section II, Virus Research. The station is surrounded on all sides by mature cacao rapidly being destroyed by swollen-shoot disease.

KORANSANG.

From 1st July, 1946 onwards for a period of 90 days only 1·81 inches rain fell. The effect on the cacao was disastrous. Most of the supplies planted earlier in the year were killed and 513 mature trees died. The yield fell from 17½ cwt. in 1945/46 to only a little over 2 cwt. in 1946/47.

Cutting out diseased trees continued during the year and 631 were so removed. In addition 336 unhealthy trees were pollarded. Of these 110 died without regeneration and 15 showed swollen-shoot symptoms on the first sucker growth and were destroyed.

About a quarter of the station has suffered severely from drought each season since the Institute commenced work in the latter part of 1944, and it is doubtful if any attempts to re-establish cacao on this area will be successful. When the rainfall is adequate, however, the cacao grows strongly throughout the whole station.

VI. BOTANICAL AND HORTICULTURAL STUDIES.

SUMMARY.

Selection for yield and bean size, but not specifically for disease or pest resistance, has led to the establishment at Tafo of six progeny trials.

The first progeny trial is confined to the self-fertilized progeny of local Amelonado types with one Trinitario selection, the second to Trinitario types with one Amelonado selection.

The progeny of one selection in the first progeny trial is outstanding and is to be multiplied by the Agricultural Department.

A small trial of white or pale bean selections has been established.

Introductions from the West Indies and South America of *Theobroma cacao* types and other species of *Theobroma* have been made and are growing well at Tafo. Certain Upper Amazon types of *Th. cacao* are particularly vigorous and early bearing.

The natural pollinators of cacao in West Africa have been identified as Cerapotogonid midges, mainly *Forcipomyia spp.* Natural cross pollination occurs chiefly between adjacent and nearly adjacent trees.

In rooting cacao cuttings the best growth-promoting substance tried had been β -indolylbutyric acid at a concentration of 0.5 per cent. in tale.

Experiments on propagation of cacao by cuttings have led to the adoption of β -indolylbutyric acid at a concentration of 0.5 per cent. in tale as a standard treatment for root stimulation. Rooting of cuttings over the year averaged 74 per cent. Of these rooted plants, 60 per cent. were successfully hardened; it should be realized, however, that the losses in hardening include many rooted cuttings which had already lost their leaves and which would not normally be potted.

Experiments are still in progress on other chemicals, on the rooting medium and on different methods of potting to reduce losses in hardening-off.

NEW INTRODUCTIONS.

The collection of cacao types introduced from Trinidad and South America was planted in the field in July, 1945. The plants have become well established and interesting differences in habit and vigour are already apparent. The types from the Upper Amazon region have shown outstanding vigour; several came into bearing in 1946 and the majority have flowered in 1947.

Of the related species of *Theobroma*, two species of *Th.* (*Herrania*) have fruited and hand-pollination has demonstrated the presence of self-incompatibility in this group. It is of interest that no capsid damage has been observed on any non-cacao species of *Theobroma*, although no preventive measures have been taken.

Th. angustifolium was successfully introduced from Dominica, B.W.I.

PROGENY TRIALS.

The six progeny trials, containing selfed progeny of selected high-yielding trees, which were planted in 1940-42, have suffered from capsid attack, but the first two trials are coming into bearing. In the First Progeny Trial where establishment is limited by poor soil and capsid attack, an examination of two years' yield figures revealed an outstanding performance by the progeny of one selection, E.1. The early bearing habit, high yield of pods per tree, and high weight of individual beans suggest that this selection will prove of value for seed distribution.

The Second Progeny Trial, comprising nine acres mainly of Trinitario selections is of great interest, as it will shed much-needed light on the genetics of this highly variable type of cacao, and disclose the possibilities of clonal seed as opposed to expensive vegetative propagation.

A plot of seedlings grown from white beans has been established and several plants have commenced bearing. The object of this plot is to provide Criollo material for selection.

POLLINATION EXPERIMENTS.

The estimation of cross-pollination by the seedling axil-spot method has been continued for the fourth consecutive year. Of the 335 pods planted from three rings of yellow-pod trees surrounding a red-pod tree, only four pods had been cross-pollinated from the red-pod tree.

A tree has now been discovered which produces 25 per cent. albino seedlings on selfing but only normal seedlings if crossed with neighbouring trees; of 14 open-pollinated pods, eight were selfed and six crossed. This tree will provide a better estimate of cross-pollination than the red-pod trees, since with the latter it is impossible to decide what proportion of pods on the surrounding yellow-pod trees have

been crossed with pollen from other yellow-pod trees. The albino gene, being recessive, will give a precise figure for the percentage of crossed and selfed pods, a fact essential for the determination of the minimum size for clonal seed distribution-plots.

VII. MYCOLOGY.

SUMMARY.

Much of the damage to cacao, formerly ascribed to capsids alone, has been shown to be due to subsequent fungal infection. One fungus mainly concerned is *Calonectria rigidiuscula* (Berk. & Br.) Sacc. This fungus can remain dormant in old occluded capsid lesions but becomes active if the tree becomes weakened.

A programme of research on the association of fungi, especially *Calonectria rigidiuscula* (Berk. & Br.) Sacc. *Fusarium decemcellulare* Brick) with capsid damage and die-back of cacao, has been continued with the object of testing conclusions already reached, and investigating other aspects of the problem.

ISOLATIONS.

Die-Back.

It has been confirmed that *C. rigidiuscula* is very frequently associated with cacao die-back. The fungus does not, however, appear to be present in every case, even in those of "chronic" type. A difficulty in interpreting the results of isolation work from this kind of material is the ubiquity of the fungus *Botryodiplodia theobromæ* Pat. in moribund tissues. This fungus is almost invariably present at least close behind the advancing edge of the die-back, and in many cases is the only fungus isolated actually from the advancing edge. *B. theobromæ* grows rapidly in culture, and tends to swamp other fungi.

Occluded capsid lesions.

With regard to capsid damage, there is no reason to question the marked distinction which has been drawn between "infected" and "uninfected" lesions. On the other hand, it is probable that the importance of *C. rigidiuscula* in connection with "infected" capsid lesions may have been over-stressed. It seems that fungi other than *C. rigidiuscula* can behave in the same way, though admittedly none is found so commonly.

Occluded lesions only on chupons up to 1 inch diameter have been studied; in lesions still open to the exterior it is possible that the fungus population, if any, would not have reached a stable equilibrium. Only one lesion was taken from any tree, in order to sample from as wide an area as possible. Entire lesions were plated out. No lesion has produced more than one fungus. Cultures were discarded as sterile if there were no growth after seven days at laboratory

temperature. Table 16 gives the percentage of lesions infected with various fungi, or apparently sterile, from a total of 100 lesions:—

TABLE 16.
PERCENTAGE OF LESIONS INFECTED.

	Percentage.
<i>C. rigidiuscula</i>	42
<i>Botryodiplodia theobromæ</i> ...	30
Other fungi	22
Apparently sterile	6

“Other fungi” includes species of *Phoma*, *Phomopsis*, *Fusarium*, *Pestalotia*, etc.

Miscellaneous.

A number of cases of rapid die-back of young seedlings has been examined. While some were damaged by capsids and some by borers, in others no insect damage was visible. A proportion of the plants in each category was infected with *C. rigidiuscula*, and this fungus has been found very frequently associated with borer damage on young cacao. *C. rigidiuscula* has also been isolated from a rotten pod lying on the ground, indicating that it is capable of a purely saprophytic existence.

INOCULATIONS.

Several experiments have been carried out in which *C. rigidiuscula* spores have been introduced into stems of young cacao plants by needle pricks from 0.1 to 1.0 cm. deep, and a technique has been established for investigating possible clonal resistance to invasion by the fungus. For this purpose needle lengths of 0.5 and 1.0 cm. are most convenient.

Detailed observations have been made on all inoculations, and cultures made from each lesion. Control punctures were inoculated with sterile water. *C. rigidiuscula* Strain 3 was employed throughout these experiments and all other artificial infection experiments, facilitating recognition of the fungus on recovery. It will be possible here only briefly to summarize the results, which are as yet incomplete.

No superficial differences between “treated” and “control” punctures were visible after any period up to six months. Internal examination only two weeks from inoculation, however, showed dark brown lesions around treated punctures, extending longitudinally for up to 2 cms. in the wood, while controls showed only a slight browning immediately round the track of the needle. Spread from treated punctures continued fairly uniformly, but control lesions appeared to develop very slowly after about two months.

C. rigidiuscula Strain 3 was consistently isolated from lesions round treated punctures; the percentage recovery increased with time, reaching a maximum of 92 per cent. two months from inoculation. All isolations from lesions round control punctures were sterile up to one month from inoculation. After two months 27 per cent. were fertile, and after four months 75 per cent., yielding *Botryodiplodia theobromæ*, *Fusarium* spp., and various saprophytes, but not *C. rigidiuscula*.

In another series of experiments, cacao seedlings have been decapitated, and the cut surface painted with a spore suspension from *C. rigidiuscula*, controls being painted with sterile water. Plants treated with spore suspension showed more rapid necrosis from the cut surface than controls (average depth of 1.0 cm. compared with 0.3 cm., after three months). A high proportion of isolations from the advancing edge of the necrotic tissue in treated plants yielded *C. rigidiuscula*; those from control plants yielded an assemblage of fungi very similar to those recovered from control plants in needle-inoculation experiments. It should be noted that both series of experiments were carried out at a distance of 100-200 yards from standing cacao.

Needle inoculations, 1.0 cm. deep, of *C. rigidiuscula* spores into the husk of cacao pods detached from the tree, washed, and kept in a humid chamber, resulted in spread of the fungus in the husk and sometimes to the beans. Extensive lesions developed after two weeks. Spores of the fungus were produced in abundance on the surface of some pods round the points of inoculation, and the same strain as used for inoculation was recovered from husk and beans. Control inoculations with sterile water and with a dry sterile needle remained sterile. Spread was slower in pods kept on the laboratory bench, but again the fungus sometimes penetrated to the beans. When the inoculations were made 0.5 cm. deep, only very small lesions confined to the husk were produced. *C. rigidiuscula* has not been isolated from any natural lesion on living pods.

EXPERIMENTAL INFECTION OF CAPSID LESIONS.

It has been possible to carry out only one preliminary experiment involving the painting of a spore suspension of *C. rigidiuscula* on recently made capsid punctures.

Splitting of the bark around the punctures took place in both treated and control series with approximately equal severity, and eight weeks after feeding all the stems had similar brownish-black lesions in the wood. Isolations were made from samples of the latter (20 from each series). *C. rigidiuscula* was recovered from 15 per cent. of "treated" lesions and from no control lesions; *B. theobromæ*, however, was isolated from 55 per cent. of "treated" and 60 per cent. of control lesions.

While a stigmatomycotic relationship cannot yet be disproved, the results of this small experiment do at least show that *C. rigidiuscula* may in certain circumstances infect recently made capsid punctures if spores are placed on the surface of the stem, and there is no reason to suppose that a comparable process may not occur in nature.

CULTURE STUDIES.

Work has been performed on the behaviour of *C. rigidiuscula*, and to a lesser degree of other fungi, in culture. *C. rigidiuscula* is a very variable fungus; four "strains," all authenticated by the Imperial Mycological Institute, have been selected as covering the range of variation fairly well. Laboratory work on this fungus has been confined to the four representative strains. It has been shown, for example, that the behaviour of each strain, especially with respect to mycelial and sporing habit, pigmentation, and spore-septation, is markedly influenced by the type of medium and the light intensity, but the four strains do not all behave similarly with regard to each factor.

VIII. PHYSIOLOGY.

The year under review includes the first ten months following the appointment of a plant physiologist. Several lines of investigation have been initiated during this period, but none has yet been brought to fruition. Accordingly this report will describe the lines on which work is proceeding rather than results obtained.

Illumination conditions in cacao plantations.

A detailed study is being made of the variation in time and space of the extent to which illumination is diminished by shade trees and by cacao itself. Observations on the ground illumination under mature cacao on three representative plots are approaching completion, and measurements of the light intensity over the cacao canopy on one of these plots are proceeding.

Growth rate of cacao seedlings.

An experiment in which seedlings are to be grown under five degrees of artificial shade, and harvested at intervals in order to determine relative growth rate, dry matter and water distribution and net assimilation rate, is in process of establishment. Preliminary observations on seedlings grown in the nursery without differential treatment have given the personnel engaged useful experience, and have provided data of value in the planning of the principal experiment.

More detailed observations have been made on the day-to-day development of the seedling during the first few weeks of growth, including the accumulation of dry matter and water and their distribution through the plant.

Leaf area—development and distribution.

Numerous observations have been made on the rate of expansion of leaves during a "flush." Leaves of young and mature trees and of seedlings have been included, and the observations cover fan and chupon shoots with widely varying numbers of leaves, both in the canopy and near ground level.

The total leaf area of certain trees in the fifth progeny trial (being representative young Amelonado trees), and its distribution between different types of shoot, is being measured. The distribution of light intensity over the leaf area is also being determined, with a view to estimating the importance of mutual shading in cacao foliage. The work will later be extended to older trees.

Observations on diurnal changes in area of cacao leaves, with a view to the possible future use of a modification of Sach's method for measuring dry-weight changes, have shown that these changes are much smaller than have been observed in temperate plants, and, indeed, are virtually negligible.

Relation of yield of native-planted cacao to proximity to shade trees.

On several plots on the station, yields of individual trees (in number of pods) have been recorded by the Agronomy Division since 1938. The analysis of these data in relation to the distance of the cacao from trees of the more important shade tree species has begun, and it is expected that in the course of the analysis, results on the relationship of yield to tree girth, spacing and soil type will also emerge.

IX. AGRONOMY—TAFO STATION.

SUMMARY.

Establishment of young cacao has been best when shade is provided by natural vegetation fortified by such shade plants as *Gliricidia*. It has been worst where the vegetation is kept cutlashed to ground level and reliance for shade placed on plantains alone.

Certain plants have been shown to be unsuitable for shade at Tafo; among these are *Crotalaria*, *Saman*, *Gmelina*, *Albizia lebbek* and *Tetrapleura tetraptera*. On the other hand, *Leucaena*, *Gliricidia* and *Erythrina* appear beneficial.

Very satisfactory results have been obtained in establishing cacao introduced from America. These results are considered due to the absence of preparatory burning, the establishment of shade provided by natural vegetation and appropriately spaced *Gliricidia*, bananas and tree cassava, to heavy vegetable mulches and to chemical control of pests.

Land has been prepared in a similar manner for planting cacao in the following experiments:—Uniformity, Spacing, Establishment, Clonal types and Entomological trials.

Yield per acre over the 60 acres of the Old Station has declined since 1938. This has been partly due to a continuous reduction in the number of bearing trees through a number of causes, one of which has been swollen-shoot disease, and may be partly due to declining rainfall. Gaps caused by the destruction of mature trees have been replanted with cacao.

Rejuvenation trials on old cacao in poor health have shown that neither heavy vegetable mulching nor interplanted *Leucaena* have prevented declining yields; pollarding resulted in the death of a high proportion of old trees in poor health.

CACAO CROP.

Old Station.

The trend of falling yields since 1938 has unfortunately been maintained, and the crop for 1946/47 is the lowest recorded. In addition to the persistent loss of bearing trees through various causes (of which swollen-shoot is of minor importance) the past season was the driest experienced since the station was opened. The supplies put in to replace lost trees have not yet come into bearing, and it is unlikely that the crop will reach the high level of 1938/39 until they do.

The drought in July, August and September resulted in a smaller ratio of weight of beans to number of pods than normal, but the loss on fermentation was less.

Most of the small mid-crop—May and June, 1946—was utilized as seed for planting.

TABLE 17.
TOTAL CROP FROM ALL CACAO (63.69 ACRES)
ON OLD STATION, 1938-1947.

Season.	No. of pods harvested.	% of pods discarded.	Total weight wet beans.	% dry to wet wt. beans.	Yield per acre dry cacao lbs.
1938-39	775,065	15.82	127,468	43.8	808
1939-40	682,109	10.67	132,627	40.8	783
1940-41	706,443	8.43	140,161	41.4	788
1941-42	767,461	13.26	139,889	40.0	795
1942-43	621,724	10.54	155,388	43.1	749
1943-44	642,180	16.42	113,995	40.4	720
1944-45	593,217	14.69	108,037	40.8	690
1945-46	547,762	29.19	76,658	40.9	492
1946-47	368,859	5.51	58,564	44.5	409
9-Year Mean	633,980	13.94	112,532	41.6	693

Delivery of the crop from the recorded plots of the old Uniformity Trial, comprising 224 one-quarter acre plots and 31 one-sixteenth-acre plots, is given in Table 18.

TABLE 18.
DELIVERY OF CROP, 1946/47.

Date of picking.	No. pods harvested.	% pods discarded.	Wet weight beans.	% dry to wet.	Av. yield per acre dry cacao.
Sept. 2-14 ...	26,476	8.9	5,418.7	46.48	43.5
Sept. 23-Oct. 1	36,222	3.0	6,977.0	42.30	50.9
Oct. 14-28 ...	66,724	4.3	12,617.1	39.40	85.8
Nov. 12-Dec. 13	181,609	4.5	24,577.9	47.21	200.3
Dec. 31-Jan. 14	32,276	10.7	4,636.1	45.61	36.5
Total ...	343,307	5.2	54,226.8	44.55	417.0

The distribution of yields on the 224 one-quarter acre plots in 50 lbs. class intervals (*i.e.*, 200 lbs. per acre) is given in Table 19. The modal class has fallen from 401-600 lbs. for the previous season to 201-400 lbs. for the present season.

TABLE 19.
DISTRIBUTION OF PLOT YIELDS ON 224
ONE-QUARTER ACRE PLOTS—1946/47.

Yield Class.	Percentage of total number of plots in each class.		
	1944-45	1945-46	1946-47
0- 200	5.8	8.5	16.5
201- 400	9.3	25.3	34.8
401- 600	23.1	35.1	26.8
601- 800	22.7	19.1	15.6
801-1000	24.4	8.0	4.9
1001-1200	7.1	3.6	0.9
1201-1400	4.9	0.4	—
1401-1600	1.8	—	0.5
1601-1800	0.9	—	—
1801-2000	—	—	—
Highest plot yield in lbs. per acre ...	1,661.52	1,251.6	1,527.6
Lowest plot yield in lbs. per acre ...	80.12	2.92	Nil

Loss of cacao trees.

Apart from the 266 trees on the old station cut out as having swollen-shoot disease 836 trees were lost through other causes.

Yields from the One Square Mile.

The area of healthy cacao remaining in the One Square Mile now totals only 300 acres. From this area 75,180 lbs. of dry cacao were obtained giving an average yield of 250 lbs. of dry cacao per acre.

FIELD EXPERIMENTS.

Rejuvenation Trial.

In the previous annual report details were given of this trial on old cacao. Yields have further declined on both the mulched plots and on those through which *Leucaena glauca* had been planted. Those plots which were completely replanted with cacao in 1941 have been utilized by the Division of Entomology for experiments on capsid control. The trees are not yet in bearing.

N.P.K. Trial on Young Cacao.

Little effect of these artificial manures has yet been observed on the growth of the cacao though there is a marked patchiness throughout the plot. The uneven growth can be ascribed to capsid attack and to lack of uniformity in the soil before the application of fertilizers.

Establishment Trials.

The method of allowing natural vegetation to grow up with the cacao, but periodically controlled to prevent smothering the cacao, has continued to show outstandingly better results than the use of plantains, *Leucaena* or *Tephrosia* planted as temporary shade.

Cacao Supplies.

Where gaps have been formed in the canopy through the removal of swollen-shoot diseased trees or through other causes the routine, since 1944, has been to plant cacao seed at a close random spacing similar to native practice. In general these seedlings are growing well.

THE ONE SQUARE MILE ACQUISITION.

The preliminary removal of swollen-shoot diseased trees—except those left for experimental purposes—was completed during the year. Reinspection and retreatment has been carried out. The areas cut out are being allowed to revert to bush until required for experimental planting.

During the latter part of 1946 land was prepared for the following experiments:—

Uniformity Trial	10.0	acres.
Establishment Trial	7.5	„
Spacing Trial	8.5	„
Clonal Trial of Selections	6.0	„
Cacao for future Entomological Trials	6.0	„

The technique of land preparation was as follows:—

- (a) Selection of the area of each experiment according to the soil map.
- (b) Under brushing the existing cacao to allow clear visibility.
- (c) Marking out with pegs the future cacao piquets.
- (d) Digging holes at each piquet.
- (e) Marking out and planting shade at appropriate distances between the cacao piquets; the shade used has been bananas (planted as corms not as suckers), *Gliricidia* and tree cassava—a non-tuberous variety of *Maniot glaziovii*.
- (f) Felling the existing cacao.
- (g) Felling forest trees on and immediately surrounding the experimental plots.
- (h) Leaving the plots until shade and climatic conditions are suitable for cacao planting the position of which can be found by the holes dug at (d) above.

Minor alterations, such as the substitution of plantains for bananas in certain experiments, have been adopted where necessary.

It is believed that this technique will avoid what is thought to be the common error of soil exposure in the preliminary stages of perennial tropical crop establishment. At no stage is the soil left uncovered and it will be noted that no burning is practised.

The planted shade has grown rapidly through the felled cacao and forest trees and the conditions for planting the cacao in the 1947 wet season appear excellent. It is proposed to provide for permanent shade by planting, at appropriate distances, a mixture of indigenous forest trees and by encouraging the natural regeneration of certain species thought to be beneficial to cacao. It is regretted that the technique calls for the destruction of existing forest trees but these are so variable in type, size and numbers that their influence on the cacao might mask the effects of the treatments under trial.

The land for the cacao introductions received essentially the same treatment in 1945 as that recorded above. As the young plants grow the surrounding vegetation is periodically cut back so that there is no mechanical check in development. The loppings, banana trash and rotting wood from the initial clearing are used as a heavy mulch round each cacao stand. The growth of the cacao has been most satisfactory under these conditions.

CACAO FERMENTING EXPERIMENTS.

At the request of the Gold Coast Department of Agriculture a series of experiments was carried out during the main season crop between September and December, 1946 to investigate the loss in weight as a result of fermentation and the relative labour requirements of producing fermented and unfermented cacao.

At the first harvest in September 200 lb. samples, and at subsequent harvests, 400 lb. samples of wet cacao were either dried directly on standard mat trays raised off the ground or fermented for seven days and then dried on similar trays. In all 20 replicate samples were made.

The average of the results was as follows:—

- (1) 100 lbs. of wet cacao gave 43·5 lbs. dry fermented cacao.
- (2) 100 lbs. of wet cacao gave 44·9 lbs. dry unfermented cacao.
- (3) The period between breaking cacao and making dry cacao was substantially the same whether the cacao was fermented or unfermented.
- (4) The labour involved in fermenting and drying was slightly less than that used in drying without fermentation.
- (5) At the existing cost of labour and price of cacao there was a potential loss in cash return through fermenting since the saving in labour did not compensate for the loss in weight of cacao.

The unfermented samples could not be legally sold as they contained too high a percentage of slaty beans. They were, therefore, wetted and fermented by the addition of palm wine. After drying a saleable product was obtained.

STATION MAINTENANCE.

Permanent buildings and roads have been kept in good repair; the habitation area has been maintained free from tall grass and bush. Routine sanitary measures, including D.D.T. house spraying, have resulted in the reduction of mosquitoes and house flies to negligible numbers.

Increasing repairs have had to be carried out on the temporary houses but these should remain habitable until permanent house construction can be undertaken.

Vegetables, Chinese yams, Maize and Soya beans were grown on spare areas. Nursery stocks of shade trees and ornamentals have been maintained.

The flock of sheep has increased from 91 head to 132, and the size of carcase is being increased by the substitution of a large Northern Territory ram for the small forest zone type.

The Institute's transport consisted of two Kit-cars, each with more than 70,000 miles to its credit, a new 10 h.p. van and a three-ton lorry which has been out of action for six months, pending the arrival of spares. New transport is urgently required.

The double quarters rest house has been occupied by visitors throughout most of the period under review.

Sawn timber, to the extent of 19,500 cubic feet, has been purchased and is now seasoning.

STATION DEVELOPMENT.

The following work has been completed :—

Levelling and grassing of the habitation area.

Construction of a further temporary bungalow bringing the total of these to 10.

Extension to the unallocated store thereby doubling its capacity.

Extension to the Propagators.

Workshop for artisans.

Conversion of previous workshop to stores.

Small building to house the Petrol-gas plant.

One unit of four blocks for African Staff quarters.

Kiln and drying shed for tile making.

Three wells sunk to increase the water supply for the habitation area.

A telephone exchange with 14 lines has been installed by the Posts and Telegraphs Department.

METEOROLOGY.

The rainfall for 1946 at 47.03" was the lowest yet recorded at Tafo. Owing to the low rainfall in July, August and the first 20 days of September the cacao suffered severely from draught. But the normal dry season, commencing in December, was scarcely felt in 1947 because excellent and well-distributed rain fell throughout February and March.

Local opinion holds that the rainfall has been decreasing over the past few years and this view is corroborated by the following figures :—

Average for the 3-year period 1938-40 : 65.74"

" " " " " 1941-43 : 61.71"

" " " " " 1944-46 : 55.01"

Meteorological data are recorded in Appendix 1.

O. J. VOELCKER,

Director of Cacao Research.

APPENDIX 1.
METEOROLOGICAL DATA.
FIGURES FOR 1946 COMPARED WITH 9-YEAR MEAN.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Highest Shade Maximum Do.	90.5 91	93.1 94	93.2 94	93.0 93	91.9 92	89.0 68	86.7 87	86.0 84	87.8 88	89.3 89	90.1 91	90.2 91
Lowest Shade Minimum Do.	59.8 57	61.1 57	66.4 67	66.6 66	67.0 65	66.6 66	66.4 66	65.0 64	67.0 67	66.8 66	65.7 66	61.9 58
Mean Relative Humidity (9 a.m. G.M.T.) Do.	85.7 78.2	83.4 79.8	80.6 80.2	80.7 78.7	81.3 80.9	84.2 86.2	85.2 84.3	85.1 85.2	84.0 83.1	82.4 84.5	80.7 80.3	82.8 82.9
Mean Relative Humidity (3 p.m. G.M.T.) Do.	52.8 47.6	48.8 48.4	51.0 53.1	54.1 56.3	58.4 69.8	64.5 74.7	64.9 67.8	63.0 71.1	68.7 62.3	69.3 75.7	64.7 64.3	61.0 58.9
Rainfall in inches Do.	1.58 0.08	3.30 0.78	5.15 8.14	5.94 3.08	7.24 4.50	7.65 8.79	4.95 2.07	2.52 0.52	5.23 2.70	8.86 10.13	5.79 4.14	2.61 2.10
Number of wet days Do.	4.3 3	6.7 8	11.4 12	11.3 10	13.9 10	18.0 21	12.7 9	12.1 10	16.2 12	17.7 23	11.2 8	7.2 7

ANNUAL RAINFALL FIGURES: 1938-46.

1938	1939	1940	1941	1942	1943	1944	1945	1946	9-year mean.
Inches 55.33	Inches 84.96	Inches 56.92	Inches 56.59	Inches 59.45	Inches 69.09	Inches 49.12	Inches 68.87	Inches 47.03	Inches 60.82

APPENDIX 2.

WEST AFRICAN CACAO RESEARCH INSTITUTE. FINANCIAL STATEMENT AT 31st MARCH, 1947.

LIABILITIES.		ASSETS.	
CREDITORS :—		DEBTORS :—	
Gold Coast Government Advances	£ 213,162 14 11	<i>Staff Advances</i>	£ 356 17 6
		<i>Subsidies</i>	173 15 0
		Stocks :—	530 12 6
		<i>Unallocated Materials in Hand :—</i>	
		Timber	3,545 7 8
		Petrol	15 1 8
		Other Materials	3,619 2 2
		CASH :—	7,179 11 6
		In hand—Imprest Account	100 0 0
		At Bank on Current Account—	
		Bank of British West Africa Limited	3,858 5 11
		SURPLUS & DEFICIENCY ACCOUNT :—	3,958 5 11
		Capital Outlay	86,619 5 3
		Recurrent Expenditure	114,874 19 9
			201,494 5 0
			£213,162 14 11

Issued subject to audit.

O. J. VOELCKER, *Director.*

G. H. NEAL, *Secretary.*

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